Taxation as a policy instrument to curb air traffic emissions in the short-term

Master's Thesis

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ABSTRACT

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Given the urgency of the drastic reduction targets for air traffic, it is necessary to assess which different actions will benefit the achievement of the targets in the short-term. Investments in new and lower-emission aircrafts take time, making them long-term solutions. The introduction of alternative jet fuels, in turn, are impaired by inadequate production levels and lack of economic viability. The benefits of climate offsetting will only be seen in the long term, despite short-term actions. This study presents different tax instruments as the only solution to reduce aviation emissions in the short-term, in the absence of abatement technology.

In this Master's thesis I examined, how taxation as a policy instrument can curb aviation emissions in the short-term. The policy instruments considered were fuel, ticket and seat tax and VAT, as well as emissions trading. The impact of the taxes were tested on three different one-way routes. The selected routes included a domestic flight and one intra- and inter-EEA flights. The analysis of short-term emission reduction measures assumed a monopolistic market structure, where the focal airlines have market power. The results were derived by optimizing the flight ticket price from the airline's profit function, which was used to estimate the number of passengers on the given routes, and thereby the weight of the aircraft as well as the final fuel consumption and the emissions.

The results showed, that emission reductions for all the given policy instruments remained very low in the short-term. This finding was not only due to insufficient tax levels, but also to the relatively low share of the passengers in the total emissions. Of the selected instruments, the smallest emission reduction was achieved by emissions trading, and the largest reductions by ticket and value-added tax. The seat tax was not found to have any impact on the emissions. Looking at airline profits, it was found that despite the highest emission reduction figures, the impact of the ticket tax on profits was relatively low compared to other instruments. The largest losses and highest tax revenues were generated from VAT on flight tickets. In addition to emissions trading, the fuel tax was the only policy instrument directly linked to emissions. The increase in fuel prices caused by the fuel tax could make alternative jet fuels, such as synthetic fuels, competitive in the markets. Achieving significant emission reductions in the short-term would require cutting entire flights. However, a significant reduction in passenger numbers could be avoided by seeking to increase the passenger load factors.

In reality, airlines have multiple ways to adjust to the given policy instruments. The future research could be extended to consider also other forms of policy adaptation and long-term adaptation strategies.

Keywords:	Aviation, Air traffic, Emissions, Taxation, Monopoly, Abatement measures, Price regulation
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Lentoliikenteen jyrkkien päästövähennystavoitteiden kiireellisyyden vuoksi on välttämätöntä arvioida, mitkä eri toimet hyödyttävät tavoitteiden saavuttamista lyhyellä aikavälillä. Investoinnit uusiin ja vähäpäästöisempiin lentokoneisiin vievät aikaa tehden niistä pitkän aikavälin ratkaisuja. Vaihtoehtoisten polttoaineiden käyttöönottoa puolestaan heikentävät riittämättömät tuotantotasot ja taloudellinen kannattamattomuus. Ilmastokompensaation hyödyt näkyvät lyhyen aikavälin toimista huolimatta vasta pitkällä aikavälillä. Tässä tutkimuksessa esitetään erilaisia veroinstrumentteja ainoaksi ratkaisuksi lentoliikenteen päästöjen vähentämiseksi lyhyellä aikavälillä, mikäli puhdistusteknologiaa ei ole.

Pro gradu –tutkielmassa tutkittiin, miten verotuksella voidaan hillitä lentoliikenteen päästöjä lyhyellä aikavälillä. Tarkasteltavia veroinstrumentteja olivat polttoaine-, lippu-, penkki- ja arvonlisävero sekä päästöoikeuskauppa. Verojen vaikutusta testattiin kolmella eri yhdensuuntaisella reitillä. Valitut reitit kattoivat yhden kotimaan- sekä Euroopan Talousalueen sisäisen ja ulkoisen lennon. Lyhyen aikavälin päästövähennystoimia koskevassa analyysissä oletettiin monopolistisia markkinoita, missä keskeisillä lentoyhtiöillä on markkinavoimaa. Tulokset johdettiin optimoimalla lentoyhtiöiden voittofunktiosta lentolipunhinta, minkä avulla estimoitiin matkustajamäärät annetuilla reiteillä, ja sitä kautta lentokoneen paino sekä lopullinen polttoainekulutus ja päästömäärät.

Tuloksista kävi ilmi, että kaikkien veroinstrumenttien kohdalla päästövähennykset jäivät lyhyellä aikavälillä hyvin mataliksi. Tämä havaintoa selittävät paitsi riittämättömät verotasot, mutta myös matkustajien suhteellisen pieni osuus reittien kokonaispäästöistä. Valituista ohjauskeinoista pienimmän päästövähennyksen sai aikaan päästöoikeuskauppa, ja suurimmat vähennykset lippu- ja arvonlisävero. Penkkiverolla ei huomattu olevan minkäänlaista vaikutusta päästöihin. Tarkasteltaessa lentoyhtiöiden voittoja huomattiin, että korkeimmista päästövähennysluvuista huolimatta, lippuveron vaikutus voittoihin oli muihin ohjauskeinoihin verrattuna melko matala. Suurimmat tappiot ja korkeimmat verotulot syntyivät lentolipun hintaan lisätystä arvonlisäverosta. Polttoainevero oli päästöoikeuskaupan ohella ainut suoraan päästöjen määrään sidottu veroinstrumentti. Polttoaineveron aikaansaama polttoaineen kallistuminen voisi tehdä vaihtoehtoisista polttoaineista, kuten synteettisistä polttoaineista kilpailukykyisiä. Lyhyellä aikavälillä merkittävien päästövähennysten saavuttaminen vaatisi kuitenkin kokonaisten lentojen operoimatta jättämistä. Matkustajamäärien merkittävää laskua voitaisiin kuitenkin välttää pyrkimällä nostamaan lentokoneiden matkustajatäyttöasteita.

Todellisuudessa lentoyhtiöillä on lukuisia eri tapoja reagoida annettuihin verokäytäntöihin. Tulevaisuudessa tutkimusta voisi laajentaa ottamalla huomioon muita lyhyen aikavälin sopeutumiskeinoja sekä pitkän aikavälin sopeutumisstrategiat.

Avainsanat: Ilmailu, Lentoliikenne, Päästöt, Verotus, Monopoli, Päästövähennystoimet, Hintojen säätely

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All that remains, is gratitude.

Helsinki, on the 10$^{\text{th}}$ of March, 2021

Helena Rantala

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1 Introduction

To limit the global temperature rise to 1.5°C, countries around the globe have committed to common goals to reduce anthropogenic carbon dioxide emissions. In 2018, commercial aviation was estimated to be responsible approximately for 2% of the total fuel combustion-related emissions globally [Graver et al., 2018]. More than a half of the overall radiative forcing of aviation is considered to be based on non-CO2 effects, such as cirrus clouds and condensation trails that are generated in high altitudes by aircraft engines from water vapor [Kärcher, 2018]. The current effective radiative forcing of aviation is approximately 3.5% [Lee et al., 2021], and is expected to rise up to more than 12% by 2050 [Penner et al., 1999]. The majority of the emissions, 85%, is accounted by passenger air transport [Graver et al., 2018].

During the last decades, aviation has experienced significant growth as a result of a rapid increase in passenger demand, directly linked to global welfare growth [Chi and Baek, 2012]. After the 1990s, aviation emissions increased more than 85% by the year of 2012 [IEA, 2014]. More than 360 billion liters of jet fuel was used in commercial aviation in 2018 [Mazareanu, 2020], responding to nearly 920 million tons of CO2 emissions. By the year 2039, air traffic emissions are estimated to nearly double up to 1523 million tons of CO2 [Scheelhaase et al., 2018], and even higher growth rates are estimated for the year 2050 if no climate mitigation action will be taken [Cui et al., 2018]. It should be noted, however, that also significant improvements have been achieved in fuel efficiency. Among International Air Transport Association (IATA) Members, the annual fuel efficiency improvement was around 1.5% on average in years 2000-2015 [Alonso et al., 2014]. A total of 37% fuel efficiency improvement had been achieved among the Association of European Airlines (AEA) between the years 1986-2013. However, the fact that aviation emissions, in turn, had more nearly doubled in less time [IEA, 2014], shows that the improvements in technology alone are an insufficient measure to achieve the desired emission reduction goals. In other words, the rapid growth in passenger demand has offset the efficiency gains and turned into a sharp rise in emissions, with an annual growth rate of approximately 3%.

In response to the growth in passenger demand and, thus the sharply growing air traffic emissions, various environmental policies could be or have been used to curb emission trends. Of these policy instruments and abatement measures, alternative jet fuels, electrification of fleets, taxation, emissions trading, and offsetting are presented and discussed in this thesis. An aviation tax could be levied, for example, on jet fuel, flight tickets, fleet seats, and adding to VAT. Save VAT, these taxes can be levied as unit taxes, based either on CO2- emissions or on other criteria. Instead of taxes, an emissions trading scheme can be applied. Under certain assumptions emissions trading is equivalent to emission tax. The aim of aviation taxation, in general, is to offer incentives for airlines to reduce their overall emissions by developing less-emitting technology, supporting the introduction of less-emitting fuels (such as synthetic fuels), increasing load factors, reducing per-passenger emissions, and as a top, make passengers avoid flying as a result of price regulation [Keen et al., 2012][Tol, 2007].

Based on existing tax practices, some estimates, both empirical and theoretical, concerning the effect of the tax have already been made. As stated by Hayashi and Trapani (1987), an increase in jet fuel price caused by a fuel tax can either increase or decrease passenger load factors depending on the reactions and adjustment of the airlines. The impact of the tax is not always fully predictable but depends on many factors, such as the airline's market power, local legislation, distribution of passengers by travel classes, and its impact on the airline's total revenues. In the case of rising jet fuel expenses, for example, the airline can try to maximize its sales revenues by increasing passenger load factors to cover the rising costs. On the other hand, if the airline manages to fully transit the tax cost to flight ticket prices, an increase in ticket prices might lead to decreased passenger load factors. If again, the transit will be made for premium class passengers with relatively low demand-price elasticities, the load factor may even remain unchanged.[Hayashi and Trapani, 1987] This emphasizes the prevailing perception showing that it is important for the tax cost to be felt by the passengers. Otherwise, it will not have the desired effect on the demand [Krenek and Schratzenstaller, 2017].

One of the major challenges of reducing aviation emissions is that 62% of global aviation emissions have been released in international airspace [Cames et al., 2015], which results in difficulties to allocate the responsibilities of mitigation actions to specific operators under certain states. In response to these challenges, some sub-national agreements have already been concluded. Since 2012, all flights operated inside the European Economic Area (also referred as intra-EEA flights) have been included to the EU Emission trading system, including all EU Member Stated plus Norway, Iceland, and Liechtenstein [European Parliament, 2009]. Around the same time in 2016, the International Civil Aviation Organization (ICAO) has set a target for carbon-neutral growth in all international aviation from 2020 onwards. The scheme - Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) - has been "estimated to offset around 80% of the emissions above 2020 levels", during the period between 2021-2035.[ICAO, 2019] On the third and current phase of the EU ETS, 15% of the allowances will be auctioned and 82% received through free allocation. The rest - 3% - of the allowances are kept aside in case of fast-growing airlines or new entrants.[European Parliament, 2009] According to Boon et al. (2007), with 100% auctioning and 45 euros allowance price, the maximum reduction in emissions would be approximately 3%.

The impact of both EU ETS and CORSIA is weakened by the narrow scope of their activities. European aviation is responsible for a third of all the global aviation emissions [Transport & Environment, 2016], of which intra-EEA flights respond to approximately 40% [Scheelhaase et al., 2014]. Thus by excluding inter-EEA flights from the trading system, around 60% of the potential emissions of the participating countries will be left outside the trading scheme. Similar challenges are also faced by CORSIA, where only international aviation will be included, excluding more than a third of all global aviation emissions from its set objectives. Considering that CORSIA, to date, is estimated to cover around 75% of all international aviation emissions worldwide, only less than a half of the global emissions will be covered. In addition, CORSIA might also offer a competitive advantage to those states, of which domestic aviation covers a more significant share of the total air traffic, such as China, Russia, and the US [Scheelhaase et al., 2018].

Besides avoiding increasing emissions, the tax deficiency also causes profit losses. The main reason for aviation being significantly under-taxed relays under the Chicago Convention (Convention on International Civil Aviation) made in 1944. According to the convention the fuel used on arriving international flights can not be set under energy taxation.[ICAO, 2006] The Chicago Convention does not ban fuel taxing on a domestic area but creates a major obstacle for worldwide jet fuel tax planning. According to a study surveying sustainability-orientated taxes, especially a carbon-based ticket tax, the estimates of profit losses resulting from tax deficiency in the EU were between 3884-5392 million euros. The results varied depending on which one of the tax estimates ($25 and $35) was used. The total profit loss responded approximately to 0.3-0.4% of the EU's annual total budget. Neither of the estimates resulted in any absolute reduction in passenger demand, but instead, manage to curb the growth rate to +0.27 - +4.23%. With the given tax rates, the ticket prices would rise by 3.5 - 4.9% (5.30 - 7.30€) on intra-EU flights and 1.7 - 2.4% (22 - 31€) on intercontinental flights. The estimates were calculated in 2014 prices. According to the same study, these tax rates would have to be significantly higher to result in an absolute reduction in demand, and thus in emissions.[Krenek and Schratzenstaller, 2017]

This study examines how different policy instruments affect the aviation emissions. The study will begin with introducing both the existing and potential future abatement measures and tax instruments. In this part we will justify the choice of a tax instrument as the suitable policy instrument to curb air traffic emissions. The third part presents the company 's (i.e. airlines) theory assuming a monopolistic market structure, where the focal airlines have significant market power. Based on this theory, the impact of the various economic instruments on the airline reactions will be examined. The starting point will be to analyze tax policy in a sharp focus of assuming a monopoly setting the ticket prices on routes, where the competition resembles a monopolistic competition. In this chapter, the examined tax forms will be presented in more detail. In the fourth part, parametric models will be taking into use, consisting mainly of numerical analysis of the introduced policy instruments. The numerical results are analyzed based on how they affect the emissions, passenger numbers, ticket prices and airline's profits. The emission reductions will be obtained by comparing the post- and pre-tax passenger numbers, and converting them into weight that translates to the ratio between the weight of the aircraft and the total jet fuel consumption, and thus further into emissions. At this point, the demand price elasticities become essential variables, since they determine the magnitude of the passengers' reactions to the increase in flight ticket prices. In the final chapters, the obtained results will be analyzed and considered in more detail, considering also some of the variables and practices excluded from this study.

2 Instruments and Measures

This chapter reviews typical measures and policy instruments to curb air traffic emissions. First, we begin by introducing the considered tax instruments, including a short review of the existing tax practices.

2.1 Type of taxes

Table 1: Policy instruments presented in this study

Tax	Tax base	Tax type	Tax rate
Levied on the airline company			
Fuel tax	The amount of fuels used	Unit tax	€/ltr, gallon
Emissions tax	Emissions from fuel combustion	Unit tax	€/CO2 emissions
Seat tax	Number of seats in the aircraft	Unit/Lump-sum tax	€/seat
Allowance price *)	Emissions from fuel combustion	Unit tax	€/CO2 emissions
Levied on buying consumers			
Ticket tax	Tickets sold	Unit tax	€/ticket
VAT	Price of tickets sold	Value tax	%/ticket price

*) Allowance prices refers to the price of allowances in the emissions trading system. All intra-EEA flights are included in the EU Emissions Trading Scheme.

In the above table 1, all the policy instruments presented in this study will be introduced. This includes taxes levied on fuel, flight tickets, seats and a value-added tax. In addition, the EU Emissions Trading System will be included as a policy instrument. Save VAT, all these taxes can be subject to a unit tax or a carbon-based tax. A unit tax has a fixed tax rate that can be based on many different factors. In the case of a ticket tax, the tax rate can be based either on route distance, sub-national conventions or travel class, for example. In the case of a carbon-based tax, the tax rate consists of two factors: the price and level of the emissions. In the case of allowances, the price of emissions will be determined by allowance markets, in which the amount of emissions represents the demand for allowances, and the number of tradable allowances the market supply. In this study, we use fixed tax rates presented later in chapter 4.

There are already some existing empirical data on the introduction of ticket and fuel taxes. For example, in Sweden, a year after the introduction of the Swedish Aviation Tax, the aviation passenger demand dropped approximately 4% between the years 2018-2019 [Swedavia Airports, 2020]. Some speculations consider, however, the general awakening to the disadvantages of air traffic emissions to be the biggest reason to cause such a rapid drop in passenger demand [Reuters, 2020]. Regardless of what caused the decline in demand, it can be shown that the passenger demand is price sensitive and, thus can be influenced through price regulation [Castelli et al., 2003]. In the US, a 1.82% decrease in passenger demand was observed, after the airfares had risen by one percent. The same study concluded that the emission reductions in the US, were the result of the decrease in demand.[Bhadra, 2002]

Besides Sweden, there were also 6 other European countries that used ticket taxes in 2019, such as Austria, France, Germany, Italy, United Kingdom and Norway [Tax Foundation, 2019a]. However, all of these taxes were not necessarily referred to as "a ticket tax". In the UK, the official term is *Air Passenger Duty*, and in Austria, the tax is called *Flight Tax Act* (Flugabgabegesetz) [HM Revenue & Customs, 2019] [RIS, 2021]. In addition, some countries have abandoned aviation taxes likes Denmark and The Netherlands since it let to the transfer of passengers to neighboring airports [Krenek and Schratzenstaller, 2017].

Besides of ticket taxes, many countries are taxing their jet fuels. Countries such as, Japan, India, Brazil and the US have all levied a fuel tax on their domestic flights [Faber and O'leary, 2018][Tax Foundation, 2019a]. Like for example in Japan, the jet fuel was not originally levied for environmental reasons, but to cover the rising aviation-related costs, such as the maintenance of airport infrastructure and acquisition costs of new fleets, as the demand in homeland increased. In Japan, a 30% cut in the fuel tax lead to a 9.3% increased level of jet fuel consumption, and increased the annual CO2 emission levels generated by domestic flights by 9.23%. The above figures and were defined as the lowest estimates in the study.[González and Hosoda, 2016] In the US, an increase of 4.3 cents in jet fuel tax used had not shown any significant reductions in fuel consumption in the long-term. A study conducting the impact of jet fuel tax in the US aviation industry shows, that together with low jet fuel price elasticity, low tax levels and level of participants, the actual reduction in emissions remains quite low. According to the same survey from Fukai and Miyoshi (2017), the jet fuel tax rate would have to be at least 3 to 5 times bigger to achieve a one percent reduction in carbon dioxide emissions.[Fukui and Miyoshi, 2017] This also applies to the emissions tax, where the level of the tax strongly determines its impact on emissions. For example, estimates are showing that a $50 price of a ton of CO2 does not yet have a significant impact on emissions, unlike $200 would do. A $200 tax would mean a price increase of 0.5-2 dollars per gallon of kerosene jet fuel, and would ultimately result as a 8% reduction from the baseline emissions. [Sgouridis et al., 2011].

2.2 Abatement measures

This section reviews typical measures already in place or planned to reduce air traffic emissions. As emission levels are directly dependent on use of the polluting input (the kerosene jet fuel), there are multiple actions that can be specifically targeted at reducing fuel consumption. Improving fuel efficiency is one way to reduce emissions, for example. The total jet fuel consumption is determined and influenced by multiple factors, such as speed and altitude, weather, fuel type and efficiency, route distance, load factors and number of stops, and the initial weight of the aircraft.[Turgut et al., 2014][Singh and Sharma, 2015] In addition to carbon dioxide, the combustion of kerosene jet fuel generates also other particles and gases that affect the overall climate impact. The most significant ones are nitrogen and sulfur oxides, water vapor, carbon monoxide, black carbon and hydrocarbon, of which the 3 first mentioned vanish faster and do not disperse far from the flight routes. Sulfate and soot aerosols, on the other hand, have a relatively small effect compared to the other emissions. However, since the formation of clouds is influenced by aerosols when accumulated, they might have an impact on cloud formation and, thus "the radiative properties of clouds".[Penner et al., 1999] In addition to pollution and direct emissions, aviation causes also noise and creates heat.

Table 2: Combustion products of kerosene jet fuel.
Source: EASA, European Aviation Environment Report 2019

Fuel combustion	In Kg	Substance
2,700kg kerosene →	8,500	CO2
	3,300	H2O
	30	NOx
	2,5	SO2
	2,0	CO
	0,4	HC
	0,1	PM and Soot

In general, a flight can be divided into many phases, of which, the Landing and Take-Off (LTO) cycle will be the most relevant on this study. LTO cycle covers all operational activities at altitude of less than 1 kilometer. Between the LTO cycle, the aircraft climbs, cruises, and descents.[Winther and Rypdal, 2019] Depending on the flight procedure, thrust power differs from another consuming varying amounts of fuel, and generating different amounts of emissions. For landing and approaches, for example, the aircraft uses only 30% of its engine power, while only 7% of the thrust power will be utilized during taxi procedures and ground idle. Full power is used usually during takeoff.[Winther and Rypdal, 2019] Since the LTO cycle may cover relatively high share of the total emissions of a flight, the per passenger-kilometer emissions tend to be higher on shorter flights, and controversially, lower on longer flights in *status quo*.

2.2.1 Energy efficiency

Over the past decades, the development of fuel efficiency has been tremendous. An average fuel efficiency improvement among IATA Members has been around 1.2% between 1986-2013, which corresponds to a total of 37% of an improvement [Miyoshi and Fukui, 2018]. The total fuel efficiency improvement has been approximately 70% since the 1960's [Peeters et al., 2016]. However, the fact that the emissions have more than doubled in less time [IEA, 2014], clearly shows that the improvements in fuel efficiency and technology alone are insufficient measures to result the rapidly increasing air traffic emissions, and stay below the climate targets [Becken and Mackey, 2017].

2.2.2 Biofuels

One way to achieve the emission reduction targets is to replace the most emitting part of aviation, the jet kerosene with a lower-emission (or even zero-emission) option. According to the current knowledge, the greatest potential appears to be in biofuels and power-to-X fuels [Scheelhaase et al., 2019]. Also, alcohol, liquid hydrogen, and algae-based fuels have been designed as jet fuel substitutes. However, most of the alternatives presented have shown either significant, or even insurmountable problems with the current level of technology to be suitable for aircraft engines and models. Addressing these shortcomings may in some cases even increase the level of emissions.[Daggett et al., 2006] The same fuels that have proven to work, for example, in road transport may not work in aviation. The fact that the operation of air traffic works in higher altitudes poses a significantly higher risk of sparks for public safety in air transport compared to road transport. Operating in high altitudes also creates more requirements for the fuel, as it needs to remain operational even in extreme temperatures and also be light-weighted enough not to cause any drop in fuel efficiency.[Mohammad et al., 2013][Kandaramath Hari et al., 2015] Other complicating factors are mainly related to the higher costs of alternative fuels compared to conventional fuels and insufficient production levels [Noh et al., 2016][Prussi et al., 2019].

Table 3: Fuel price comparison between conventional and bio-based fuels, by Takriti et al., (2017).

	Price/ton
Conventional jet fuel	\$470-\$860
Sugar & starch based fuels	\$800-\$4,800
Vegetable oil based fuels	\$1,000-\$2,000
Ligno-cellulose & waste based fuels	\$1,000-\$8,000

Biofuel is classified as a zero-emissions source of energy although the energy production process generates carbon dioxide emissions, including emissions from primary production, refining, and transportation generates emissions [Deane and Pye, 2016].

On the basis of biofuels' life cycle emissions, the actual emission reduction potential relies somewhere between 30 - 90%, when compared to conventional jet fuel [Vera-Morales and Schäfer, 2009][Stratton et al., 2010]. The level of absolute emission reductions is highly dependent on factors, such as the source of biofuel. The first-generation biofuels are typically made from sources suitable for food production, such as oily, or other high-energy crops, such as palm oil or sugarcane, or corn. On the other hand, the sources of the second-generation biofuels are mostly human or industrial waste, or sources with a high concentration of lignocellulose, such as logging waste and other wood waste.[Mohr and Raman, 2015] When comparing the potential in reducing emissions, the second generations stand out positively in terms of sustainability [Mohr and Raman, 2015]. However, the scarcity of second-generation biofuels supply makes them much more expensive compared to the other fuel types. In 2050, the estimated total maximum supply of lignocellulosic fuel for the aviation industry is 4Ej, corresponding to 18% of the total expected jet fuel consumption on international aviation in 2050.[Takriti et al., 2017] Besides supply scarcity, the manufacturing process is technologically more challenging, and thus also more expensive.[Mohr and Raman, 2015][Takriti et al., 2017].

Since fuel can cover up to 45% of airlines' operational costs [Sibdari et al., 2018], it is a very influential factor to affect airlines' viability. Higher costs of biofuels can result in significantly impair their introduction in the aviation sector.[Takriti et al., 2017] These types of challenges confirm a lack of interest, which on the other hand, undermines investors' development, deployment, and investments in biofuels. First and foremost, the price of oil is too low, which affects the ability of other alternative fuels to compete in the market. Secondly, the production costs of biofuels are much higher compared to conventional fuels, especially among biofuels with higher potential to reduce emissions significantly.[Takriti et al., 2017]

According to Deane and Pye (2018), the price of carbon should be $200 per ton for biofuels to be competitive for conventional jet fuels. Currently, the cap between the price of conventional jet and biofuels is approximately between 0.42 and 1.20 euros per liter. This additional cost could be offset by adding 1.20-4.30 euros on all passengers in all intra-EU and domestic flights on a typical flight length of 1000 kilometers.[Deane and Pye, 2018] Biofuel production could be supported by setting international requirements for the blending mandate and providing tax credits for biofuel suppliers. In addition, further funding for Research and Development is required. The number of import duties on biofuels could also be reduced, and above all, a set of taxation to support the introduction of biofuels is highly required. Noh et al. (2016) continued, that studies are showing that the blending mandate alone could be enough to meet the targets of the demanded biofuel consumption. It has even been equated as effective as a combination of fuel taxation together with biofuel subsidies. The fact that blending mandates have the potential to patch up uncertainties surrounding the use of biofuels by creating secured demand and thus stir up the supply side, can make them very effective policy measures.[Noh et al., 2016] According to De Jong et al. (2017) if biofuels would be produced primarily as a secondary product, instead of primary, it could have a positive effect on finance. Biofuel adoption may also remain low, due to a lack of proper external incentives. It is estimated, that with broad (large-scale) incentives the degree of biofuel inclusion could reach up to 20 percent of the total amount of fuels in 2030.[De Jong et al., 2017]

2.2.3 Power-to-X

Power-to-X (also shortened to $P2X$) is an incoming form of technology, which can be made by combining carbon dioxide with hydrogen or nitrogen to form synthetic fuels. This process can be made by using only sustainable energy, such as wind or solar energy [Daiyan et al., 2020]. Such technology can, at best, provide a revolutionary way of developing fuel since it offers solutions to fundamental problems concerning energy storing and subsequent use of renewable energy [Gür, 2018]. In power-to-X technology both carbon dioxide and nitrogen are captured straight from the atmosphere, and hydrogen from the water. Thereafter they can be generated into end products such as methanol, dimethyl ether, methane, and ammonia, where the energy is restored for later use. The revolutionizing features of the technology are that despite the generated emissions from common fuel combustion, the formation of the fuel itself binds carbon dioxide for the air which results in carbon-neutral end products.[Daiyan et al., 2020] As for where it takes centuries for biomass to capture carbon from the air, with power-to-x technology the process can be done in an instant.

According to Schmidt and Weindorf (2016), power-to-liquids could also be utilized in aviation, and are suitable for the existing infrastructure and engines. However, the key factor for the successful introduction of power-to-fuel depends primarily on the price ratio between new and conventional jet fuels [Scheelhaase et al., 2019]. Despite the enormous potential of power-to-fuels to reduce industry dependence on fossil fuel combustion, speed up industrial decarbonization and thus emissions, the price of the new alternative fuel needs to become competitive before its extensive introduction in aviation, for example.[Gust et al., 2009][Scheelhaase et al., 2019] As a result, sufficient incentives, or other financial instruments, such as carbon-based taxation, or the EU ETS are truly needed to accelerate the introduction of this type of emission mitigation measures. Whether power-to-fuel becomes competitive fuel for conventional jet fuels depends on factors such as its overall production potential, suitableness for existing aircraft engines, and price fluctuations of jet fuels and carbon allowances. One of the factors affecting the profitability of power-to-x jet fuels is whether the product is treated as a zero-emission source of energy, and thus exempted from emissions trading.[Scheelhaase et al., 2019]

2.2.4 Electricity

There are high expectations for the electrification of air transport. Through electrification, operating aircraft could at best be made completely CO2 emission-free, eliminating also the non-CO2 effects of aviation. Battery charging and electricity production, however, generate some CO2 emissions that will be included in the life-cycle emissions of the batteries.[Schäfer et al., 2019] If the non-CO2 emissions will be included in the emission calculations, the warming effect from an all-electric aircraft (AEA) per revenue passenger kilometer can be 30% less than when operated using conventional jet fuel. Controversially, if the non-CO2 emissions will be excluded, the life-cycle emissions may turn up to be even slightly higher.[Schäfer et al., 2016]

The current challenges in the electrification of air transport concern, above all, battery performance. According to Kivits et al. (2009), the energy density of lithium batteries responds only to 1% of the density of conventional kerosene jet fuel, and thus can not be considered as a relevant substitute [Kivits et al., 2010]. The low energy density of batteries should be compensated with larger battery sizes. This proportional weight should be cut off from other factors such as luggage or passenger weight. Another problem is caused by the relatively long charging times [Fisch et al., 2019]. Avoiding overheating of batteries also creates its own challenges for deployment. Thermal stress of the battery may pose a safety risk since overheating can cause the battery to catch fire. To avoid overheating, specialized cooling systems are required. Cooling systems can also extend battery lifetime shortened by thermal stress. However, the cooling system would not only require more energy but would also increase the load weight of the aircraft, and thus the overall energy consumption [Canders et al., 2019].

Despite the previously mentioned challenges, some electric flights have already been successfully operated, yet on rather low altitudes and on short distances. Due to airspace congestion [Ryerson et al., 2014], it is difficult to assess in what magnitude AEAs' can replace traditional flights if passenger capacity cannot be increased. The main current challenges are to improve the performance and energy efficiency of the batteries. This includes developing lighter batteries with longer duration, better thermal stress resistance, and shorter recharging times.

There is a lack of clear, consistent literature on the subject, which makes it difficult to present valid sources. Thus, most of the information on this section is based on general media and corporate websites.

2.2.5 Offsetting

The purpose of an offset system is to reduce the negative impact of emissions, by implementing other climate mitigation actions. In general, this means that the emissions will be offset by purchasing so-called carbon credits that reduce the emissions elsewhere.[IATA, 2020] Typical offset programs deal with reforestation, forest protection, or projects that support the development or deployment of cleaner, low-emission technology [Becken and Mackey, 2017]. According to Professor Becken and Mackey (2017), the most credible targets to offset emissions are projects supporting forest protection and other activities that restore carbon from the atmosphere. Previous measures have been seen especially effective when occurring and implementing in the developing countries [Becken and Mackey, 2017].

Compensation as a climate mitigation measure is criticized for directly not to reduce or forbid polluting activity, but instead allows companies to keep emitting, and thus, should not be considered as the first, but rather as a second, or third option for airlines' climate mitigation action.[Becken and Mackey, 2017] The potential, relatively low abatement costs of offsetting (depending on the service provider and the airlines' compensation criteria) can encourage airlines to reduce their calculated emissions by compensating. In addition, the current level of offsetting has been estimated as insufficient to reach the desired climate targets [Sonnenschein and Smedby, 2019].

To ensure carbon-neutral growth in aviation, the demand for compensation in BAU is estimated to be around 25 Gt of CO2 in 2020-2050 [Cames et al., 2015]. In some cases, offsetting might provide a misleading impression about the real damage caused by aviation, and belittle the level of damage through the price. In these cases, the absolute value of compensation can be heavily insufficient to cover the real social costs of carbon caused by air travel. Besides the economic aspects, also the definitions can be sometimes scientifically misleading. According to Professors Becken & Mackey (2017), rather few airlines have clearly stated, that the emissions generated might have climate impacts despite the compensations made.[Becken and Mackey, 2017] It must also be considered, that the expected benefit of reforestation, for example, is experienced over time, even on a 40 to 80 years delay [Silver et al., 2000], when the rapid emission reductions should be performed immediately to meet the global climate targets.

2.2.6 Extra-Short-haul flights

One way to avoid unnecessary air traffic emissions would be to ban or limit extra-short-haul flights that could be operated by using less-emitting substitutes, such as rail transport. In this study, an extra-short-haul flight is considered as a flight with a route distance of less than 200 kilometers. Since shorter flights typically have higher per-passenger-kilometer emissions compared to longer flights due to the high-emitting LTO cycle (see page 8), it could be considered as an option to reduce emissions.

Depending on the time and location, shorter distances have typically more alternative forms of transportation to choose from. It can be assumed, that some of the passengers on extra-short haul flights are transit passengers. In these cases, the ticket prices and time variables are not necessarily as significant variables as fast connections and effortless transit to the next aircraft. However, by providing proper subsidies to existing substitutes such as rail transport, the integrity of the rail infrastructure and travel efficiency could be improved to offset the loss in transport mode.

Another positive impact of banning or limiting extra-short-haul flights, in addition to a reduced level of air traffic emissions, is the reduction of air traffic congestion. Congestion in airspace forces airplanes to circulate the airport area while waiting for permission to land, or to extend routes, which both may instead cause additional delays at airports and reduce terminal efficiency. The average emission reduction potential on airspace used jet fuel can be even up to 20 percent by eliminating delays, flight time extensions, and departure delays. However, the same study conducts that the impact of delays on jet fuel consumption may be much less than the differences in terminal efficiency.[Ryerson et al., 2014]

2.3 Summary

In response to the requirements to curb air traffic emission levels tremendously, it becomes essential to assess the time periods where the solutions can be obtained. Due to the urgent nature of the matter, it can be considered rather unlikely to achieve the common emission reduction targets in the required short-term period, if the abating actions would require massive improvements in technology. Investments in new, more energy-efficient, and less-emitting fleets require more time and, thus they can be considered as long-term forms of adaptation. This applies both to improving energy efficiency and to the introduction of electrification of fleets. In addition, whereas biofuels suffer from a lack of economic viability and insufficient production levels, the climate benefits from compensating will be obtained in a long-term period, despite the short-term actions.

When there is no abatement technology, this study proposes different taxes and tax-life incentives as the only carbon-free solution to the current issue.

3 Aviation Taxation: Theoretical Framework

This chapter consists of the theoretical framework applied in this study. It assumes an imperfect market with a monopolistic market structure, where focal airlines have market power. This type of simplified monopoly model can be considered to correspond to the current situation in Finland. The formal model used in this work is based on [Carlsson, 1999], where the focal airlines maximize their profits by choosing the price and number of routes (or flights). The model is applied to the situation of concatenated flights, where the choice of flight route is rigid and only pricing can be used to respond to changes in exogenous variables. The production, i.e. operated flights is directly dependent on the use of the polluting input - kerosene jet fuel-, when there is no abatement technology. The analysis also excludes running down the route networks, which are crucially important in terms of the competitive position of the focal airlines. In addition to fuel use and ticket price, the airline also has other decision variables based on which it optimizes and plans its operations, where some are fixed. Such variables are, for example, travel classes, aircraft types and operating frequency, seasonal changes, and jet fuel price fluctuations, and are all excluded from this study. This includes addressing issues, such as revenue distribution, based on both travel classes and routes, and the potential reactions of the airlines in this type of situation.

In this thesis, we assume that the authorities are trying to internalize the negative externality from the use of the polluting input through environmental policies. Now, the price control takes place through aviation taxation. The industry faces two inefficiencies: both the negative externality from emissions and the loss of economic efficiency. The review of the situation mainly focuses on negative externalities and their minimization using the second-best policy on emissions. A first-best policy would also include the distortions in production.

3.1 Airline profits without environmental policy

Consider first an airline maximizing its profits from a flight on a given route and given capacity of the aircraft. Let the seating capacity be X. The airline derives revenue from paying passengers who pay a ticket with an average price of p. The demand for flights depends on the price and determines the average percentage of seating capacity bought. Let $\alpha(p)$ denote this share, so that the actually sold amount of seats for a given flight on this route is $\alpha(p)X$, i.e. $\alpha(p)$ is the demand function. The amount of kerosene needed for the flight depends on the length of the route and the weights of the aircraft. Let the baseline, kerosene jet fuel consumption be denoted by g. This indicates the jet fuel consumption the aircraft would use without any passengers on board. The total jet fuel consumption will later turn into emission by applying the emissions factor ϵ, a total of 3.15. Let the route distance be denoted by d. Now, we can express the total jet fuel consumption as of function of G(p) (see equation (2)), where c denotes the price of kerosene, and parameter ϕ translates the capacity to weights, which determines for a given route the actual jet fuel consumption. We assume that $\frac{dg}{dX} > 0$ and $\frac{dg}{d\alpha} > 0$, thus a larger aircraft consumes more fuels and a higher load factor increases the consumption of kerosene, and that $\alpha' < 0$ and $\alpha'' > 0$. The price of flight ticket and kerosene are also positive. Let finally M denote all other flight-dependent costs including among other, salaries of staff.

Under this notation, profits of the airline on the given route are given by:

$$\pi = p\alpha(p)X - cG(p) - M \tag{1}$$

Where the total jet fuel consumption can be written as:

$$G(p) = g + \frac{d}{1000}(\alpha(p)X\phi) \tag{2}$$

The monopolistic airline chooses ticket price to maximize its profits. The necessary, first-order condition for the optimal solution is given by,

$$\frac{d\pi}{dp} = (p\alpha'(p) + \alpha(p))X - cG'(p) = 0 \tag{3}$$

The marginal jet fuel consumption in equation (3):

$$G'(p) = \frac{d}{1000}(\alpha'(p)X\phi) < 0 \tag{4}$$

The sufficient, second-order conditions for the optimum are negative, as required:

$$\frac{d^2\pi}{dp^2} = (p\alpha''(p) + 2\alpha'(p))X - cG''(p) < 0 \tag{5}$$

in which,

$$G''(p) = \frac{d}{1000}(\alpha''(p)X\phi) > 0 \tag{6}$$

For an economic interpretation of the first-order condition (see equation (3)), note that the first two terms $((p\alpha'(p)+\alpha(p))X)$ denote the marginal revenue from choosing the price. It is decreasing in price. The third term represents marginal change in fuel cost due to marginal increase in price. This term is positive in price but negative and increasing in weight, that is, the amount of passengers. This can be interpreted so that an increase in ticket prices leads to a decreased number of passengers, which in turn lightens the aircraft and thus, reduces the total fuel consumption and costs. In the absence of any environmental policy, the value of the marginal revenue equals the marginal costs comprising the constant unit price, $MR = MC$, which can also be written as:

$$(p\alpha'(p) + \alpha(p))X = cG'(p) \tag{7}$$

It is useful to determine the impacts of an increase in fuel cost on pricing. Differentiate the first-order condition with respect to p and c. This produces,

$$\Omega dp - G'dc = 0 \tag{8}$$

were the sufficient second-order conditions presented in equation (5), can be denoted by Ω. Thus we get,

$$\frac{dp}{dc} = \frac{G'}{\Omega} > 0 \tag{9}$$

Thus, we can now obtain the result showing that without any environmental policy, the airline profits are primarily affected by the changes in jet fuel prices. In addition, an increase in fuel costs increases the flight ticket price, and reduces passenger load factors.

3.2 Airline profits with environmental policy

Consider next how alternative aviation taxes enter the profit function of the airline. Recall, we have four different instruments: fuel tax, emission taxes or emissions trading and taxes on flight tickets. They all enter the profit function differently resulting in different reactions by the airlines.

3.2.1 Fuel tax

Suppose first that the authorities decide to levy a tax t for the polluting input, the conventional kerosene jet fuel, and that the tax will be added to the average kerosene jet fuel price c. In this case, the total cost of the polluting input will be defined now as $(c+t)G(p)$. Since the tax will be levied on airline expenses, it does not affect the demand function and thus, can be expressed as usual, $p\alpha(p)X$. The tax will also have no impact on the other airline expenses M, and thus we can write the profit function as follows:

$$\pi = p\alpha(p)X - (c+t)G(p) - M \tag{10}$$

The monopolistic airline chooses ticket price to maximize its profits. The necessary, first-order condition for the optimal solution is given by,

$$\frac{d\pi}{dp} = (p\alpha'(p) + \alpha(p))X - (c+t)G'(p) = 0 \tag{11}$$

The sufficient, second-order conditions for the optimum are negative, as required:

$$\frac{d^2\pi}{dp^2} = (p\alpha''(p) + 2\alpha'(p))X - (c+t)G''(p) < 0 \tag{12}$$

For an economic interpretation of the first-order condition (11), note that the first two terms $((p\alpha'(p) + \alpha(p))X)$ denote the marginal revenue from choosing the price. It is decreasing in price. The third term represents marginal change in fuel cost due to marginal increase in price. This term is positive in price but negative and increasing in weight, that is, the amount of passengers. Thus, the optimum requires that $MR = MC + tG'(p)$. The tax increases marginal costs of the flight, therefore the airline increase price it increase MR. The conclusion is that the fuel tax increases ticket price relative to the case of no environmental policy.

This finding can be ascertained by examining, how an increase in fuel tax impacts the price set by the airline. Let us differentiate the first-order conditions with respect to p and t. This produces,

$$\Omega dp - G'dc = 0 \tag{13}$$

were the sufficient second-order conditions presented in equation (12), can be denoted by Ω. Thus we get,

$$\frac{dp}{dt} = \frac{G'}{\Omega} > 0 \tag{14}$$

Compared to the initial situation (see equation (7)), the MC increases while MR remains the same as before, leading to an increase in ticket prices, and decrease in occupancy rates.

3.2.2 Emission tax and emissions trading

Emission tax

Suppose now that authorities decide to use an emission tax, or implement an emissions trading scheme under which the airline must pay an allowance price. If all allowances are auctioned, tax and allowance price are identical. Let tax be denoted by λ, and the allowance price by q. The amount of taxes or carbon allowances paid depends on the overall jet fuel consumption denoted by G(p), that will be translated into emissions according to the emission factor ϵ. Neither of the instruments have no impact on the demand function, and thus can be expressed as $p\alpha(p)X$. Since the authorities assume for the levied tax to be paid by the airline, its share will be subtracted from the profit function. In this case, we assume that all allowances will be auctioned in allowance markets. Thus, we can express the profit function as:

$$\pi = p\alpha(p)X - (c + \lambda\epsilon)G(p) - M \tag{15}$$

The monopolistic airline chooses ticket price to maximize its profits. The necessary, first-order condition for the optimal solution is given by,

$$\frac{d\pi}{dp} = (p\alpha'(p) + \alpha(p))X - (c + \lambda\epsilon)G'(p) = 0 \tag{16}$$

The sufficient, second-order conditions for the optimum are negative, as required:

$$\frac{d^2\pi}{dp^2} = (p\alpha''(p) + 2\alpha'(p))X - (c + \lambda\epsilon)G''(p) < 0 \tag{17}$$

For an economic interpretation of the first-order condition (see equation (16)), note that the first two terms $((p\alpha'(p)+\alpha(p))X)$ denote the marginal revenue from choosing the price. It is decreasing in price. The third term represents marginal change in fuel cost due to marginal increase in price. This term is positive in price but negative and increasing in weight, that is, the amount of passengers. Thus, the optimum requires that $MR = MC + \lambda\epsilon G'(p)$. The last term in the optimal condition denotes the marginal emission tax cost. Like in the case of fuel tax, emission tax increases marginal cost and the airline responds to this by increasing ticket price relative to the case of no environmental policy.

This finding can be ascertained by examining, how an increase in emissions tax impacts the price set by the airline. Let us differentiate the first-order conditions with respect to p and λ. This produces,

$$\Omega dp - \epsilon G' d\lambda = 0 \tag{18}$$

were the sufficient second-order conditions presented in equation (17), can be denoted by Ω. Thus we get,

$$\frac{dp}{d\lambda} = \frac{\epsilon G'(p)}{\Omega} dp = \epsilon \frac{dp}{dc} > 0 \tag{19}$$

Thus, higher emission tax leads to a higher ticket price. Compared to the initial situation (equation (7)), MC increases while MR remains the same as before. This will increase the ticket price and reduce passenger load factors. Now, the increase in ticket cost is equal to the increase in fuel costs times the emission factor.

Emissions trading and free initial allocation of allowances

Next, the authorities face a situation where only part of the allowances will be auctioned, and part is given as free allocation, denoted by e_o. Now, we can express the profit function as follows:

$$\pi = p\alpha(p)X - cG(p) - q(\epsilon G(p) - e_0) - M \tag{20}$$

The monopolistic airline chooses ticket price to maximize its profits. The necessary, first-order condition for the optimal solution is given by,

$$\frac{d\pi}{dp} = (p\alpha'(p) + \alpha(p))X - (c + q\epsilon)G'(p) = 0 \tag{21}$$

The sufficient, second-order conditions for the optimum are negative, as required:

$$\frac{d^2\pi}{dp^2} = (p\alpha''(p) + 2\alpha'(p))X - (c + q\epsilon)G''(p) < 0 \tag{22}$$

For an economic interpretation of the first-order condition (see equation (21)), note that the first two terms ($(p\alpha'(p)+\alpha(p))X$) denote the marginal revenue from choosing the price. It is decreasing in price. The third term represents marginal fuel cost due to marginal increase in price. This term is positive in price but negative and increasing in weight, that is, the amount of passengers. Thus, the optimum requires that $MR = MC + q\epsilon G'(p)$. The last term denotes the marginal allowance cost from emissions trading. Allowance cost increases marginal cost and the airline responds to this by increasing ticket price relative to the case of no environmental policy.

This finding can be ascertained by examining, how an increase in allowance price impacts the price set by the airline. Let us differentiate the first-order conditions with respect to p and q. This produces,

$$\Omega dp - \epsilon G' dq = 0 \tag{23}$$

were the sufficient second-order conditions presented in equation (22), can be denoted by Ω. Thus we get,

$$\frac{dp}{dq} = \frac{\epsilon G'(p)}{\Omega} dp = \epsilon \frac{dp}{dc} > 0 \tag{24}$$

Thus, higher allowance price leads to a higher ticket price. Compared to the initial situation (equation (7)), MC increases while MR remains the same as before. This will increase the ticket price and reduce passenger load factors. Now, the increase in ticket cost is equal to the increase in fuel costs times the emission factor.

3.2.3 Seat tax

Suppose now that authorities decide to impose a flat seat tax θ on all routes and that the tax will be charged at every seat according to the passenger seat capacity, denoted by X. Since both the number of passengers or jet fuel costs will have no impact on the tax expenses, both the revenue and cost function will be written as normally. As in the previous cases, the tax levied by the authorities will again have no impact on the other airline expenses M and thus, we can write the profit function as follows:

$$\pi = (p\alpha(p)X - cG(p) - M - X\theta \tag{25}$$

The monopolistic airline chooses ticket price to maximize its profits. The necessary, first-order condition for the optimal solution is given by,

$$\frac{d\pi}{dp} = (p\alpha'(p) + \alpha(p)) - cG'(p) = 0 \tag{26}$$

The sufficient, second-order conditions for the optimum are negative, as required:

$$\frac{d^2\pi}{dp^2} = (p\alpha''(p) + 2\alpha'(p)) - cG''(p) < 0 \tag{27}$$

For an economic interpretation of the first-order condition (see equation (26)), note that the first two terms $((p\alpha'(p)+\alpha(p))X)$ denote the marginal revenue from choosing the price. It is decreasing in price. The third term represents marginal change in fuel cost due to marginal increase in price. This term is positive in price but negative and increasing in weight, that is, the amount of passengers. This can be interpreted so that an increase in ticket prices leads to a decreased number of passengers, which in turn lightens the aircraft and thus, reduces the total fuel consumption and costs. In the case of a seat tax, the value of the marginal revenue equals the marginal costs comprising the constant unit price, $MR = MC$ (see equation (7)):

This finding can be ascertained by examining, how an increase in allowance price impacts the price set by the airline. Let us differentiate the first-order conditions with respect to p and θ. This produces,

$$\frac{dp}{d\theta} = 0 \tag{28}$$

Now, we can obtain that the seat tax will have no impact on the ticket prices. Since emissions and passenger numbers are depending on the inner variable p, they will also remain unchanged. As a lump-sum tax, the seat tax cost can be reduced to smaller aircrafts, cannot be fully avoided. It will have a decreasing impact on the airlines's profits.

3.2.4 Ticket tax

Let us now assume, that the authorities decide to levy a (unit) tax on all flight tickets. The ticket tax τ, is added to the average flight ticket price p. The tax rate can be defined according to many different variables, such as distance, travel class, or operated regions, for example. Since the tax is not added only to the price paid by the passengers, the revenues will be calculated based on the average flight ticket price. However, the tax added to the ticket price will impact the demand function and thus, the revenue function can now be expressed as $p\alpha(p+\tau)X$. As the level of fuel consumption depends on the demand, the ticket tax now also affects the costs of the airline. The cost function can be expressed as: $cG(p+\tau)$. The tax will, however, have no impact on the other airline expenses M, and thus we can write the profit function as follows:

$$\pi = p\alpha(p+\tau)X - cG(p+\tau) - M \tag{29}$$

The monopolistic airline chooses ticket price to maximize its profits. The necessary, first-order condition for the optimal solution is given by,

$$\frac{d\pi}{dp} = (p\alpha'(p+\tau) + \alpha(p+\tau))X - cG'(p+\tau) = 0 \tag{30}$$

The marginal jet fuel consumption:

$$G'(p+\tau) = \frac{d}{1000}\alpha'(p+\tau)X\phi < 0 \tag{31}$$

The sufficient, second-order conditions for the optimum are negative, as required:

$$\frac{d^2\pi}{dp^2} = (p\alpha''(p+\tau) + 2\alpha'(p+\tau))X - cG''(p+\tau) < 0 \tag{32}$$

$$G''(p+\tau) = \frac{d}{1000}\alpha''(p+\tau)X\phi > 0 \tag{33}$$

For an economic interpretation of the first-order condition (see equation (30)), note that the first two terms $((p\alpha'(p+\tau)+\alpha(p+\tau))X)$ denote the marginal revenue from choosing the price. As in the previous cases, it is decreasing in price. The third term represents marginal change in fuel cost due to marginal increase in price. Now, the marginal cost is also affected by the tax, that impacts the passenger demand and thus, the fuel consumption. This term again is positive in price but negative and increasing in weight. Thus, the optimum requires that $MR(p,\tau) = MC(p,\tau)$.

As the demand depends on the ticket price received by the passengers $(p+\tau)$, an increase in price can now be seen to have a decreasing impact on the demand, and thus lower the number of seats sold on a given route $\alpha(p+\tau)X$. This will have a decreasing impact on the jet fuel costs $cG(p+\tau)$, but will also decrease the passenger revenues $p\alpha(p+\tau)X$.

This finding can be ascertained by examining an increase in emissions tax impacts the price set by the airline. Let us differentiate the first-order conditions with respect to p and τ. This produces,

$$\Omega dp + ((p\alpha'' + \alpha')X - cG'')d\tau = \Omega dp + (\Omega - \alpha' X)d\tau = 0 \tag{34}$$

were the sufficient second-order conditions presented in equation (32), can be denoted by Ω. Thus we get,

$$\Omega dp = (\alpha' X - \Omega)d\tau \tag{35}$$

Finally, we get the following results:

$$\frac{dp}{d\tau} = \frac{X\alpha' - \Omega}{\Omega} = -(1 - \frac{X\alpha'}{\Omega}) < (>)0 \tag{36}$$

In equation (36), both Ω and $alpha'$ are negative making the term positive. Given that this term has a minus mark the whole expression is "priory ambiguous" and can be both positive or negative depending on whether the last term is greater that smaller than one. This means that the use of ticket tax can either increase, or decrease the ticket price received by the airline depending on the price sensitivity. From the given result, we can obtain that the price received by the airline increases, only if, the occupancy rates do not drop too fast as a result of price increase. If the tax threatens to lower the occupancy rate too low, the airline may benefit from even lowering the airfares.

3.2.5 Value-Added Tax

Now, we assume that the authorities have decided to pose a value-added tax (also known as VAT) on all flight tickets. We assume $0 < \text{VAT} < 1$. The authorities and airlines will face now two prices: the price without a VAT equal to p, which corresponds to the price received by the airline from the airfares, and price with a VAT, equal to pv, where $v = 1 + \text{VAT}$. This latter presents the price faced by the passengers. Now, the passenger revenues can be expressed as $p\alpha(pv)X$, and the fuel costs for the airline as $cG(pv)$. Again, the tax will have no impact on the other expenses M. Now, we can express the profit function as follows:

$$\pi = p\alpha(pv)X - cG(pv) - M \tag{37}$$

The monopolistic airline chooses ticket price to maximize its profits. The necessary, first-order condition for the optimal solution is given by,

$$\frac{d\pi}{dp} = (p\alpha' v + \alpha)X - cG' v = 0 \tag{38}$$

The marginal jet fuel consumption:

$$G'(pv) = \frac{d}{1000}\alpha' v X \phi \tag{39}$$

The sufficient, second-order conditions for the optimum are negative, as required:

$$\frac{d^2\pi}{dp^2} = (p\alpha'' v^2 + 2\alpha' v)X - cG'' v^2 < 0 \tag{40}$$

$$G''(pv) = \frac{d}{1000}\alpha'' v^2 X \phi \tag{41}$$

For an economic interpretation of the first-order condition (see equation (38)), note that the first two terms ($(p\alpha' v + \alpha)X$) denote the marginal revenue from choosing the price. As in the previous cases, it is decreasing in price. The third term represents marginal change in fuel cost due to marginal increase in price. Now, the marginal cost is also affected by the value-added tax, that impacts the passenger demand and thus, the fuel consumption. This term again is positive in price but negative and increasing in weight. Thus, the optimum requires that $MR(p, v) = MC(p, v)$.

As the demand depends on the ticket price received by the passengers pv, an increase in price can now be seen to have a decreasing impact on the demand, and thus lower the number of seats sold on a given route $\alpha(pv)X$. This will have a decreasing impact on the jet fuel costs $cG(v)$, but will also decrease the passenger revenues $p\alpha(pv)X$.

This finding can be ascertained by examining an increase in emissions tax impacts the price set by the airline. Let us differentiate the first-order conditions with respect to p and v. This produces,

$$\Omega dp + (p[(pa''v + 2a')X - cG''v] - cG')dv = \Omega dp + (\frac{p}{v}\Omega - cG')dv = 0 \tag{42}$$

were the sufficient second-order conditions presented in equation (40), can be denoted by Ω. Thus we get,

$$\Omega dp = (cG' - \frac{p}{v}\Omega)dv \tag{43}$$

Finally, we get the following results:

$$\frac{dp}{dv} = \frac{cG'}{\Omega} - \frac{p}{v} < (>)0 \tag{44}$$

Now, we can obtain that the impact of a higher VAT is ambiguous, because it is determined by the difference of positive term by marginal costs ratio to second-order impacts of price and price tax ratio. If the latter terms dominates $\frac{dp}{dv} < 0$, and vice versa if the former term dominates. In other words, the prices received by the airline, can either increase or decrease. With lower prices, the probability for VAT leading to an increase in prices is higher. On the contrary, on routes where the original prices are already high, adding VAT to price may even lower the ticket prices.

4 Parametric Analysis

In this chapter, the theory will be translated into the parametric analysis based on the means presented in the previous chapter: fuel tax, emission tax and emissions trading, and taxes on seats, tickets, and VAT on flight tickets. The analysis also addresses potential tax revenues and compares the impact of the given policy instruments. As discussed in chapter 3, the airline maximizes its profits only by optimizing its price variables. The prices are will be derived using the airlines' profit function, which determines the number of passengers and thus, the total fuel consumption, its costs, and emission levels. Again, seasonal changes, travel class distribution, and their impact on prices and demand will be excluded from the study. This is due to a lack of data, which would allow a more accurate analysis. The price elasticities on the given routes are treated as constant and consider all passengers equally. The distances and jet fuel consumption values are based on genuine routes and consist of real data received from an actual airline. Although we assume the price to be the only effective variable in this study, the fuel consumption is, in fact, also affected by other multiple variables, such as speed and altitude, weather, fuel type and efficiency, flight distance, load factors, and the number of stops.[Turgut et al., 2014][Singh and Sharma, 2015] In addition, the real profit functions include also other components excluded from this study and thus, the profits considered actually reflect more of the airline's revenues or running profits. The results have been obtained by using Maple software (2020).

The chosen routes are [1]:

Domestic flight, North-Europe, 555 km
Intra-EEA flight, 1222 km
Inter-EEA flight, Europe - East-Asia, 7408 km

This type of routes are, for example:

TMP - RVN, 584 km
LGW - GRZ, 1229 km
TXL - PEK, 7376 km

The route distances are approximated to present typical route distances on the given forms of commercial flights. In examples they presented in *Great Circle Distances*, and do not include factors such as, wind components or airspace congestion, which can affect the route distances but are included on the actual routes.

[1]Real route distances based on confidential anonymous communication

4.1 Monopoly's optimum in the absence of policy

In this section, we go through maximizing monopoly profits from the airline's perspective, assuming that the focal airlines have significant market power. The monopoly will maximize its profit by either setting the price or production level to a spot where the marginal revenue corresponds to its marginal costs. In this study, the only profit regulating variable is the ticket price. The price optimization is specifically affected by the level of the tax, demand elasticities, and the allocation of the tax. In this analysis, we exclude, among other things, the capital and personnel costs. Therefore the real profits are actually lower. However, since we use this practice in all cases, it does not create bias in the analysis nor to the interpretation of the results. First, we must define both the demand and costs functions. The constant elasticity demand function can be expressed as follows:

$$\alpha(p)X = Q(p) = Ap^{\eta} \tag{45}$$

Since there was no feasible price data available, the demand A had to be calibrated using an price estimate, and by calculating passenger numbers from the existing occupancy rates and seat capacity, as seen in equation (45). The used estimates for the given routes are presented on table 4.

Table 4: Data on demand and cost variables

	555 km	1222 km	7408 km
Seat capacity, X [2]	174	174	336
Passenger load factors (2017) [2]	0.67	0.79	0.82
Number of passengers, $Q(p)$	117	137	276
Ticket price, p	65 €	155 €	535 €
Demand-price elasticity, η [3]	-1.232	-1.96	-1.26
Jet fuel price, €/ liter, c_1 [4]	0.4	0.4	0.4

Table 5: Calibrated variables

	555 km	1222 km	7408 km
Demand, A	20544.26	$2.95 * 10^6$	808253.85
Running costs in €, c_2	0.053	0.26	0.19

The cost function has two parts. First, the fuel cost that will be determined according to the total jet fuel consumption presented in equation (49) multiplied by the price of kerosene, c_1. In addition, we assume quadratic running and penalty costs related to filling capacity. Let us denote the calibrated quadratic multiplier by c_2.

[2]Finnair Q4 and FY 2017 result, 16.2.2018 [Finnair, 2018]

[3]Estimating Air Travel Demand Elasticities - Final Report [IATA, 2007]

[4]Jet fuel price data from August 2019, [IATA, 2019]

Now we can express the profit maximization function as follows:

$$\pi = pQ(p) - c_1 F(total) - c_2 Q(p)^2 \tag{46}$$

The actual prices will be optimized from the profit function, determining also the actual occupancy rates, fuel consumption and emission levels, and the airline profits.

Jet fuel consumption

Let us assume, that the total jet fuel consumption is determined by the route distance and the weight of the aircraft. The total weight is affected by the size of the aircraft, the number and weight of passengers, and the amount of fuel that the aircraft consumes on the given routes when there are no passengers on board. In this study, we exclude air freight. The estimates of real fuel consumption and the route distances are based on genuine flight data. It should be emphasized, however, that the calculations include rough estimates and that the values used are mainly indicative. Now, with passenger weight estimates, we can apply the marginal fuel burn-rate of 0.025 to re-estimate both the consumption of an empty aircraft without passengers [Steinegger, 2017], and the development of fuel consumption required for passengers operating. Let the mean total mass for passengers including a carry-on luggage be denoted by W(average), equal to 83.8kg [Berdowski et al., 2009]. In the case of inter-EEA flight, also a hold, equal to 16.6kg, is included for 50% of the passenger, and its weight will be denoted by V(average). The PLF's used to estimate F(empty) are based on Finnair's average occupancy rates on similar routes in 2017. With the given estimates we can now estimate the passengers fuel consumption as follows:

$$F(passengers) = \frac{\alpha(p)X(W(average) + V(average))}{\frac{1000}{distance}} \tag{47}$$

Now, we can express the fuel consumption without passengers as:

$$F(empty) = F(real) - F(passengers) \tag{48}$$

Table 6: Fuel consumption figures in kilograms on the given routes, of which F(empty) is constant

	F(real) [4]	F(empty)	F(passengers)
555km	2300	2163.961175	136.0388250
1222km	3100	2749.26767	350.7323300
7408km	52000	47716.54624	4283.453760

By using the values presented in table 6, the total fuel consumption can be calculated using the following expression:

$$F(total) = F(empty) + F(passengers) \tag{49}$$

[4]Real fuel consumption data based on confidential anonymous communication

Baseline: monopoly's free optimum

In table 7, the baseline values of the given routes are presented assuming that there is no environmental policy. The values present the monopoly's optimum, and will be used as reference in comparison to the given policy instruments.

Table 7: Monopoly's optimum in the absence of policy

	555 km	1222 km	7408 km
Ticket price in €	67.25	157.13	553.52
Number of passengers, Q(p)	115	146	283
Passenger load factor	0.661	0.839	0.842
Fuel consumption, passengers' share in kg	133.80	373.87	4820.61
Total fuel consumption in kg	2297.77	3123.14	52537.16
Total CO2 emissions in kg	7237.96	9837.88	165492.06
Airline profits in €	6117.74	16152.86	120244.00

From the table 7 we can see that ticket prices increase together with the route distance, and that the passenger load factors (PLF) are higher on longer routes. According to the theory presented in chapter 3, the fuel consumption and emissions are positively correlated with the route distance and occupancy rate, and thus increase on the longer distance and higher load factors. Since the ticket prices are, in this case, more expensive on longer routes, and the absolute number of passengers is also higher, the airline profits are higher on longer routes. These interpretations are case examples and may not be applicable in all cases. In addition, the profits are given without capital costs, which are considerable. This does not, however, impact the comparison of instruments, as all cases are treated equally.

4.2 Impact of tax instruments on airline's profitability and emissions

This section looks numerically at the implications of different tax instruments for airlines operating on a given routes. All the results include optimized ticket prices, the number of passengers, load factors, fuel consumption, emissions, and airline profits, and are expressed to two or three decimal places. The fuel consumption will be divided into 3 categories: the baseline consumption when there are no passengers on board, passenger share of fuel consumption, and the total fuel consumption combined from the two previous ones. All the cases are considered as one-way flights, as some of the policy instruments are limited to either departing or arriving flights, depending on tax practices at the origins and destinations. The numerical values of the monopoly's optimum in the absence of policy (see table 7), can be used as a reference for the activity with an environmental policy.

Emission tax and emissions trading

Next, we look at a situation where an emission cap has been set for all air traffic emissions. Allowance price is determined in the allowance market by supply and demand. In the simulation a price of EUR 35 is used. There are now two airline profits: the airline profits assuming 15% auctioning, and airline profits when there is no free allocation, i.e., all the allowances will be auctioned on the allowance markets. All the other variables have been calculated assuming that there is no free allocation.

Table 8: Emissions trading - 35€/allowance price

	555 km	1222 km	7408 km
Emission tax/ 100% auctioning of allowances			
Ticket price in €	67.56	157.33	554.84
Number of passengers, Q(p)	114	146	282
Passenger load factor	0.655	0.839	0.839
Fuel consumption, passengers' share in kg	133.04	372.95	4810.05
Total fuel consumption in kg	2297.00	3122.22	52526.60
Total CO2 emissions in kg	7235.57	9834.99	165458.78
Airline profits in €	5864.46	16015.46	118405.45
Airline profits with 15% auctioning in €	6079.76	16101.22	119968.25

From the table 9 we can interpret that on the given allowance price, the increase in ticket prices was almost non-existent. Thus, the effects on passenger numbers and emissions also remained negligible. The only small change was reflected in the airline's profits, which were reduced by the allowance costs, or ticket revenues. With 15% allowance auctioning, the effects were even smaller. The only effect worth of considering, was in the airline's profits, where it was nonetheless almost non-existent.

Since the price is the only variable by which the monopoly maximizes its profits, it can be assumed that a significantly higher allowance price together with full auctioning would have a larger impact on the price, and thus on the other considered variables.

Table 9: Percentage change in variables, EU ETS

	EMISSIONS	NUMBER OF PAS.	PRICE	PROFITS / 15% A.
555km	-0.000	-0.009	+0.005	-0.041 / -0.006
1222km	-0.000	0	+0.001	-0.009 / -0.003
7408km	-0.000	-0.003	+0.002	-0.015 / -0.002

Fuel tax

Next, we look at a situation where a fuel tax has been levied on conventional jet fuel. The tax rate is based on the European Union minimum excise duty and is equal to EUR 0.36 per liter [European Comission, 2020]. Now, the cost of jet fuel is equal to EUR 0.76 per liter, which is almost double the original price of kerosene.

Table 10: Fuel tax - 0.36€/liter

	555 km	1222 km	7408 km
Ticket price in €	68.27	157.78	567.35
Number of passengers, Q(p)	113	145	274
Passenger load factor	0.649	0.833	0.815
Fuel consumption, passengers' share in kg	131.39	371.21	4673.60
Total fuel consumption in kg	2295.35	3120.48	52390.14
Total CO2 emissions in kg	7230.35	9829.51	165028.95
Airline profits in €	5293.63	15039.45	101371.58

From the table 10 we can interpret that on the given fuel tax rate, the increase in the ticket price is the highest on the longest route. This can be seen as a result of an increase in passenger fuel consumption on longer flights, which, in this case, almost doubles the costs involved. Thus, the change in passenger numbers and emissions are greater on the inter-EEA flight, but still very small. The most significant difference is found in the airline's profits, where the profits fall by more than 10% for the domestic and inter-EEA flight. We can assume that the drop is due to the increased jet fuel expenses faced by the airline. The change in emissions remains negligible for all routes, less than one percentage point.

Table 11: Percentage change in variables, fuel tax

	EMISSIONS	NUMBER OF PAS.	PRICE	PROFITS
555km	-0.001	-0.017	+0.010	-0.135
1222km	-0.001	-0.007	+0.004	-0.070
7408km	-0.003	-0.032	+0.025	-0.157

Seat tax

Next, we look at the situation where a seat tax will be levied on all operated flight seats. Unlike in the other cases, here the tax rates are not based on any existing value but they are the author's suggestions. In this case, the tax cost will be targeted at the airline and tax must be paid for each seat, whether it is booked or not.

Table 12: Seat tax - 5/15/25 €

	555 km	1222 km	7408 km
Ticket price in €	67.25	157.13	553.52
Number of passengers, Q(p)	115	146	283
Passenger load factor	0.661	0.839	0.842
Fuel consumption, passengers' share in kg	133.80	373.87	4820.61
Total fuel consumption in kg	2297.77	3123.14	52537.16
Total CO2 emissions in kg	7237.96	9837.88	165492.06
Airline profits in €	5247.74	14642.56	111844.00
Seat tax rate in €	5	15	25

From the table 13 we can interpret the same results we obtained already in chapter 3; the seat tax does not affect the airline's pricing and its imposition thus does not increase the ticket prices. Thus, there are no changes in passenger numbers, fuel consumption, or in the generated emissions. The tax only affects the airline's profits, where the change is about 10% on all the given routes. However, some differences occurred. On shorter routes, the reductions in profits were larger. This is hardly related to the route distance, but to the fact that longer flights have higher passenger load factors. With lower PLFs' the total tax cost with the number of paying passengers decreases.

Table 13: Percentage change in variables, seat tax

	EMISSIONS	NUMBER OF PAS.	PRICE	PROFITS
555km	±0	±0	±0	-0.142
1222km	±0	±0	±0	-0.103
7408km	±0	±0	±0	-0.070

Ticket tax

Now, we look at the situation where a ticket tax will be levied on airline tickets. The ticket tax rates are based on the 2019 European averages depending on whether the flight is a domestic, intra-EEA or inter-EEA flight [Krenek and Schratzenstaller, 2017] [Tax Foundation, 2019a]. There are now two ticket prices: the ticket price without a ticket tax, and a ticket price with the ticket tax. The difference between the prices corresponds to the ticket tax rate. The price without a tax corresponds to the revenue received by the airline from the ticket price, and the taxable price to the ticket price encountered by the passengers.

Table 14: Ticket tax - European average

	555 km	1222 km	7408 km
Ticket price without a ticket tax in €	84.71	153.98	599.55
Ticket price with a ticket tax in €	93.82	165.75	632.44
Number of passengers, Q(p)	76	132	239
Passenger load factor	0.437	0.759	0.711
Fuel consumption, passengers' share in kg	88.37	337.93	4076.60
Total fuel consumption in kg	2252.33	3088.00	51793.15
Total CO2 emissions in kg	7094.83	9724.68	163148.42
Airline profits in €	5231.17	14560.64	111722.92
Ticket tax rate in €	9.11	11.77	32.89

From the table 15 we can interpret that on the given ticket tax rate, the most significant price increase was on the shortest route. As a result, reductions in profits, passenger numbers, and emissions were also greater than on other routes. On the longer routes, the ticket prices without the tax were much closer to the original price when there are is no environmental policy. It is likely that at a lower price the revenue loss would have been larger even if the passenger demand had been slightly higher. In addition, the ratio of the tax to the original price is highest on the shortest route, which raise prices proportionally more.

We can also obtain that, the route 1222km was the only route were the ticket price without a tax decreased compared to the original ticket price. This can be explained by the fact, that on this route, the demand price elasticity was significantly higher compared to the other routes.

Table 15: Percentage change in variables, ticket tax

	EMISSIONS	NUMBER OF PAS.	PRICE WITH T. TAX	PROFITS
555km	-0.020	-0.339	+0.395	-0.145
1222km	-0.012	-0.096	+0.055	-0.099
7408km	-0.014	-0.155	+0.143	-0.071

Value-added tax

Now, we look at the situation where a value-added tax will be levied on airline tickets. The tax rates are based on the European average value-added tax rate, equal to 21.3 percentages [Tax Foundation, 2019b]. There are now two ticket prices: the ticket price without a VAT, and a ticket price with the VAT. The price without a VAT corresponds to the revenue received by the airline from the ticket price, and the taxable price to the ticket price encountered by the passengers.

Table 16: VAT on tickets - European average, 21.3%

	555 km	1222 km	7408 km
Ticket price without VAT in €	60.56	138.36	498.57
Ticket price with VAT in €	73.46	167.83	604.77
Number of passengers, Q(p)	103	128	253
Passenger load factor	0.592	0.736	0.753
Fuel consumption, passengers' share in kg	120.00	328.60	4311.68
Total fuel consumption in kg	2283.96	3077.86	52028.23
Total CO2 emissions in kg	7194.47	9695.27	163888.92
Airline profits in €	4772.23	12244.15	93077.95
VAT cost in €	12.90	29.47	106.20

From the table 17 we can interpret the passenger load factors decreased approximately by 10% on all the given routes. The profits, however, decreased more than 20%, which is the biggest reduction from all studied policy instruments. One explanatory variable is the significantly lower revenues received by the airlines per flight ticket. In this case, the airline does not have the same power to pass on the tax to the ticket prices but suffers from the tax either as disproportionately high ticket prices or as low ticket revenues.

We can also obtain that, on all routes, the ticket prices without a value-added tax decreased compared to the original ticket prices. The change in prices was very similar, approximately 10% on all the given routes.

Table 17: Percentage change in variables, VAT

	EMISSIONS	NUMBER OF PAS.	PRICE WITH VAT	PROFITS
555km	-0.006	-0.104	+0.092	-0.220
1222km	-0.014	-0.123	+0.068	-0.242
7408km	-0.010	-0.106	+0.093	-0.226

4.2.1 Comparison of tax effects

In this section, we compare the effect of different tax instruments on the given routes for the following parameters: emissions, number of passengers, ticket prices, and the airline's profits. The key focus is on short-term solutions, where the airlines have no available technology or other ways to adjust to the policy instruments than just by regulating the price to a new optimal level. At this point, the demand-price elasticities became essential variables since they largely determine the change in the price caused by the tax instrument, and thus also in other variables. In addition to examining absolute and relative changes on the given four parameters, we also look at whether there is any correlation between these parameters starting with emissions and passenger numbers, then moving on to ticket prices and profits. The ticket prices are presented as the prices faced by the passengers. The yellow cells present the routes where the relative change to the original situation brought by a given instrument was the greatest of all. In terms of the ETS, we assume 100% allowance auctioning.

Table 18: Comparison of absolute (kg) and relative changes in emissions with the given policy instruments

	ORIG.	ETS	FUEL	SEAT	TICKET	VAT
555km	7237.96	-2.39	-7.61	±0	-143.13	-43.49
1222km	9837.88	-2.89	-8.36	±0	-113.20	-142.61
7408km	165492.06	-33.28	-463.11	±0	-2343.63	-1603.12
555km	1	-0.000	-0.001	±0	-0.020	-0.006
1222km	1	-0.000	-0.001	±0	-0.012	-0.014
7408km	1	-0.000	-0.003	±0	-0.014	-0.010

From the table 18 we can interpret that the emission reductions remained remarkably low for all the policy instruments on all routes. The absolute highest reduction rate was on the domestic flight when ticket tax was used on the airline tickets. The total reduction was only 2 percentage points. The reduction can be considered negligibly small considering that the number of passengers dropped by more than a third (see table 19) and the ticket price was nearly 1.5 times higher compared to the original price. In the case of ETS, fuel, and seat tax, the reduction was less than 1 percentage at all routes. This can be justified by the fact that passenger emissions cover a really small part of the total emissions on the route. The vast majority of fuel consumption and emissions come from the weight of the aircraft itself including the equipment.

Table 19: Comparison of absolute and relative changes in number of passengers with the given policy instruments

	ORIG.	ETS	FUEL	SEAT	TICKET	VAT
555km	115	-1	-2	±0	-39	-12
1222km	146	0	-1	±0	-14	-18
7408km	283	-1	-9	±0	-44	-30
555km	1	-0.009	-0.017	±0	-0.339	-0.104
1222km	1	1	-0.007	±0	-0.096	-0.123
7408km	1	-0.003	-0.032	±0	-0.155	-0.106

Notwithstanding the results, the values determined may be useful in assessing the relationship between emissions and passenger numbers in general. For example, by taking a look at the tables 19 & 18, the following causality can be seen: the largest relative change in passenger numbers correlated with the largest relative change in emissions. The observation was valid at all routes.

Table 20: Comparison of absolute (€) and relative changes in ticket prices with the given policy instruments

	ORIG.	ETS	FUEL	SEAT	TICKET	VAT
555km	67.25	+0.31	+0.71	±0	+26.57	+6.22
1222km	157.13	+0.2	+0.64	±0	+8.62	+10.70
7408km	553.52	+1.32	+13.83	±0	+78.93	+51.25
555km	1	+0.005	+0.010	±0	+0.395	+0.092
1222km	1	+0.001	+0.004	±0	+0.055	+0.068
7408km	1	+0.002	+0.025	±0	+0.143	+0.093

As we can see from the table 20, the highest relative price increases were caused by ticket and value-added tax on all routes. Contradictory, the lowest relative price increases were caused by fuel tax and emissions trading, in which addition, seat tax had no impact on the pricing at all. We can also interpret that in the case of ETS and fuel tax, the price increases were the highest on the longest routes. This can be assumed to be due to higher fuel consumption levels on long-haul routes, which result in higher policy costs. The higher price increase on the shortest route compared to the intra-EEA route can be partly explained by differences in average jet fuel consumption per passenger-kilometer that typically higher on longer routes. Thus, the costs generating from fuel consumption are relatively higher on longer routes. However, as the route distance lengthens, the share of the baseline consumption (with no passengers on board) decreases. Thus, on very long-hauls, the impact of fuel tax becomes more significant.

By taking a look at table 21, we can see that the highest profit loss on almost every route was caused by the same policy instrument that raised the ticket prices the most. The only exceptions were the seat tax, in which case the price did not increase at all, but the tax cost reduced the airline's profits and VAT, where the profit loss was highest on the intra-EEA flight despite the higher ticket price increase on the inter-EEA flight. However, the figures are not otherwise completely uniform. As we can detect from tables 20 & 21, in many cases a higher price increase does not necessarily lead to higher profit losses. For example, in the case of a ticket tax, the relative change in airline's profits was higher on intra-EEA flight, despite the fact, that the increase in ticket price was higher on the inter-EEA flight. This can be explained by differences in multiple variables, such as the demand-price elasticities and initial occupancy rates. For all the given routes, the intra-EEA flight had the highest demand-price elasticity. This means, that the passengers react stronger on price fluctuations than on the other routes. Thus, is becomes more profitable for the airline to bear a larger share of the tax costs itself than to withstand the revenue losses caused by the fall in passenger demand.

Whereas the absolute highest price increase was obtained with a ticket tax levied on domestic routes, the highest profit losses on all routes were obtained when a value-added tax had been used. The absolute highest profit loss was obtained with a value-added tax levied on inter-EEA flights.

Table 21: Comparison of absolute (€) and relative changes in airline profits with the given policy instruments

	ORIG.	ETS	FUEL	SEAT	TICKET	VAT
555km	6117.74	-253.28	-824.11	-870.00	-886.57	-1345.51
1222km	16152.86	-137.3	-1113.40	-1510.29	-1592.22	-3908.71
7408km	120244	-1838.55	-18872.42	-8400.00	-8521.08	-27166.05
555km	1	-0.041	-0.135	-0.142	-0.145	-0.220
1222km	1	-0.009	-0.070	-0.103	-0.099	-0.242
7408km	1	-0.015	-0.157	-0.070	-0.071	-0.226

As we can see from the table 19, the highest relative decrease in passenger numbers was the same, where the relative profit losses were the highest. The only exception was obtained in seat tax, where again, the tax had no impact on passenger numbers at all. As in the case of ticket prices, also here the highest relative changes were caused by the ticket and value-added tax on all routes, and the lowest caused by ETS and fuel tax.

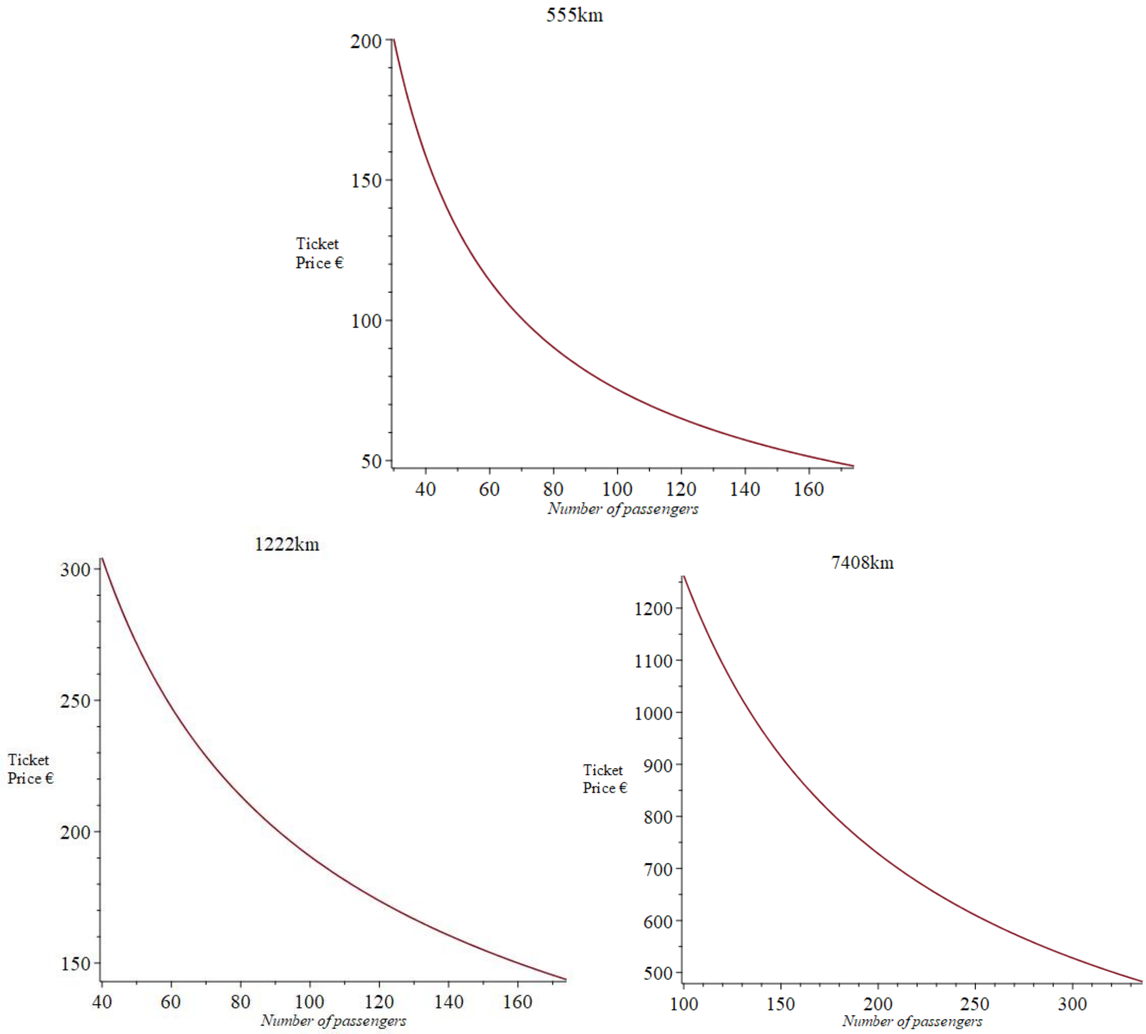

Figure 1: Demand curves for the given routes

Demand curves

By taking a look at figure 1, we can obtain that the tax instruments do not affect the demand curves, but instead, remain the same on all routes. In the case of a monopoly, the price will be regulated by moving along a demand curve in an elastic area, i.e. where the demand-price elasticity is more than one ($\eta > 1$).[Varian, 1987]

From the demand curves we can interpret, that the lower the price, the higher the occupancy rates. In addition, we can also see the lowest prices at which the aircraft could be fully booked. These figures are approximately: 45€ for 555km, 140€ for 1222km and 480€ for 7408km. Thus, we can interpret, that the willingness-to-pay for a ticket price is higher on longer routes, which can be obtained even more clearly in figure 2. In graphs, 555km and 1222km, the values on the x- and y-axis are the same, but the demand curve is higher on the longer route.

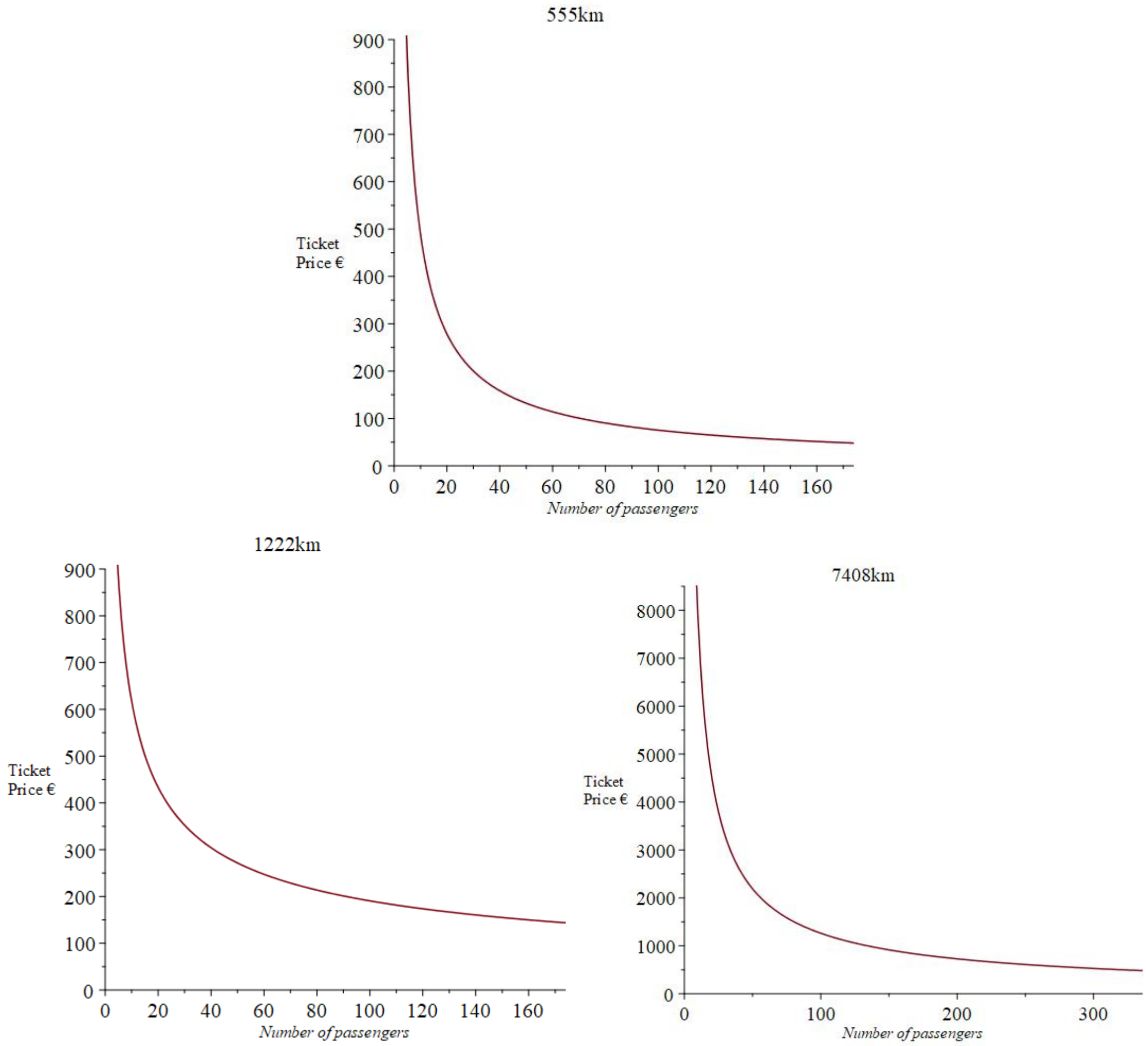

Figure 2: Total demand curves for the given routes

From figure 2 we can also interpret, that the decrease in demand is relatively steep to the price increase, especially with really high or lower occupancy rates. The differences in the steepness of the demand curves can be explained by different demand price elasticities. For example, the shapes of the slopes on routes 555km and 7408km are nearly identical since their demand elasticities differ very little from another (-1.232 vs. -1.26).

On all routes, the last highest tithe of passengers was willing to pay about 4-8 times the amount of the lowest ticket price that would have resulted in 100% occupancy rate. This observation may partly explain why it is economically viable for airlines to operate at such low occupancy rates.

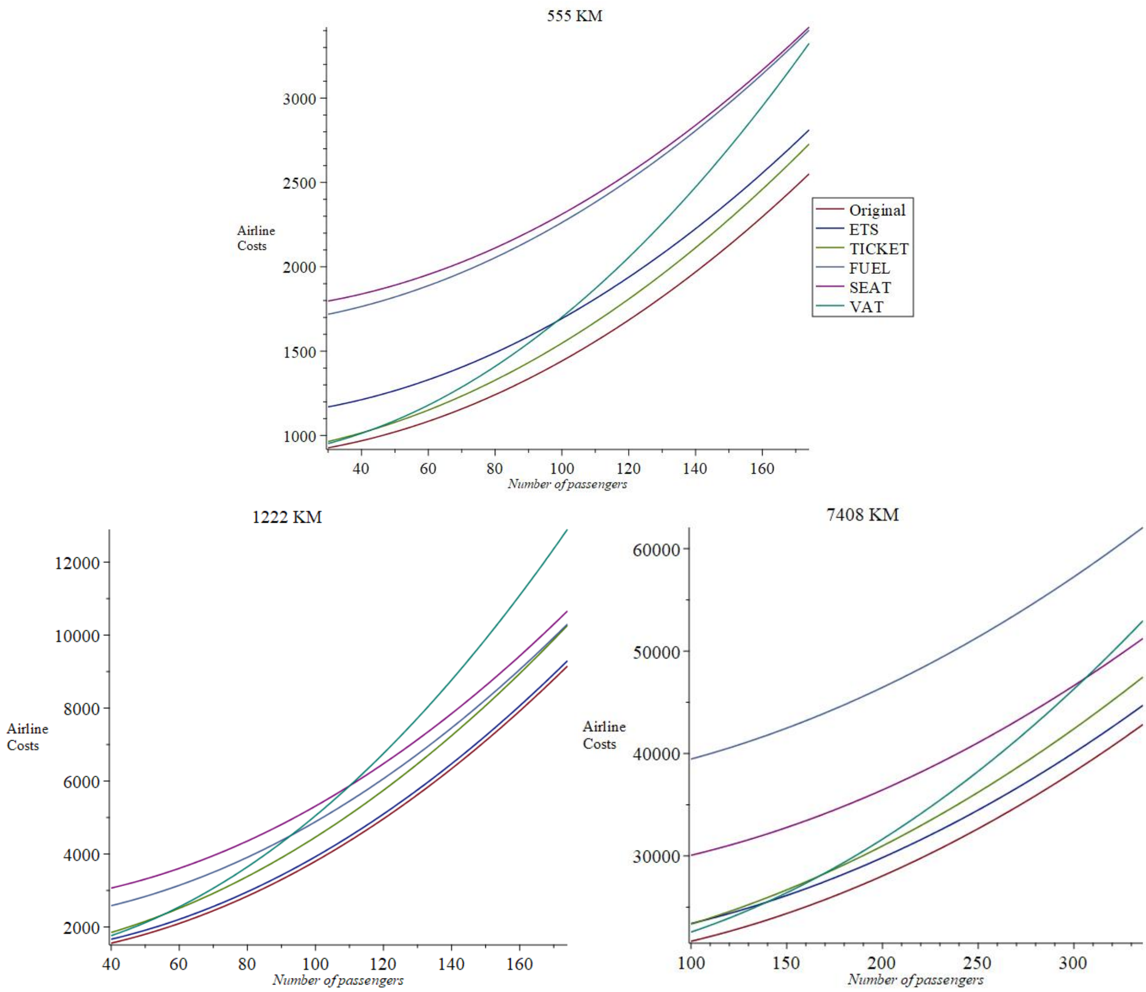

Figure 3: Cost curves for the given routes

Cost curves

By taking a look at figure 3, we can make a clear interpretation showing that the cost functions are convex, and the lowest on all routes and passenger numbers, when there is no environment policy. In addition, in the case of fuel tax and emissions trading, the cost curves shifts upwards keeping its slope unchanged, as their costs are linked to fuel consumption. In other respects, the impact of tax instruments on costs differs very much between the given routes. In the case of ETS, we assume 100% auctioning.

On the shortest route, 555km, with all passenger numbers, the highest costs result with fuel and seat tax. Controversially, the lowest costs occurred with ETS and ticket tax. With really low passenger numbers, the total costs with VAT were really near the original situation without any policy instruments but rose sharply together with the passenger numbers. The costs on a fully booked plane were approximately a third higher than the original situation when a fuel or seat tax was used.

On the intra-EEA route, 1222km, the difference in costs was not as dispersed as on the domestic route. The only difference from fairly closely evolving costs was VAT, where again, the total costs rose very sharply together with the number of passengers and were the highest of all with a 100% occupancy rate. In addition, the costs in ticket tax rose steeply and with full occupancy rate, the costs were even with a fuel tax. With the exception of VAT, the costs were the highest with the seat tax and the lowest when emissions trading was used. On the inter-EEA route, 7408km, the most significant and largest cost was incurred for all passenger volumes when the fuel tax was used. The difference to the original situation was equal to the price ratio rate between the jet fuel price with and without the tax. Again, the second-largest costs were generated by VAT and the seat tax, and the lowest with emissions trading.

The costs generated by different instruments are affected by multiple variables. Where the reduction in the number of passengers caused by the ticket tax also curbs other expenses, such as jet fuel costs, the seat tax cost must be paid by the airline regardless of the number of paying passengers on board.

By taking a look at the graphs on figure 3, it is not clear at all, that the same policy would be optimal for all routes. When evaluating suitable instruments for different routes we should, in addition to costs, take look also at the tables 18-21, to find out what are the other impacts of the given policy instruments. For example, whereas the seat tax significantly increased the airline's costs on all routes, it does not affect the number of passengers and thus does not reduce the airline's emissions. Controversially, the ticket tax had very little impact on the total costs of the airline, but by taking a look at the table 18 and 19 we can obtain, that it had the most significant downward effect on passenger numbers and emissions almost on all routes. However, it must be acknowledged that the reductions caused by a ticket tax were obtained with fixed tax rates. The only instrument that had a clear upward effect in relation to the route distance (and emissions) was the fuel tax. In the case of a fuel tax, the higher reduction in emissions was obtained, the longer the route and the higher the fuel consumption.

4.2.2 Tax revenues

In this section, we review the tax revenues arising from the use of the given instruments. The total tax and allowance revenues are obtained for optimized ticket price-based passenger numbers, fuel consumption and generated emissions.

Table 22: Tax and allowance revenues from the given policy instruments in €

	ORIG.	ETS	FUEL	SEAT	TICKET	VAT
555km	0	253.24	826.33	870	692.36	1328.69
1222km	0	344.22	1123.37	2610	1553.64	3772.19
7408km	0	5791.06	18860.45	8400	7860.71	26867.55

The tax revenues are calculated using the following functions:

$$EUETS\ allowance\ revenue = F(total)\epsilon\frac{q}{1000} \tag{50}$$

$$Ticket\ tax\ revenue = Q(p)\tau \tag{51}$$

$$Fuel\ tax\ revenue = F(total)t \tag{52}$$

$$Seat\ tax\ revenue = X\theta \tag{53}$$

$$Value - added\ tax\ revenue = Q(p)(v-1)p \tag{54}$$

were Q(p) refers to the number of tickets sold, i.e. number of passengers. By taking a look at the table 22, we can interpret that the highest tax revenue (on all routes) could be collected by using the value-added tax. Seat tax revenues were the second largest with the exception of the inter-EEA flight, where the highest tax revenues were collected by using the fuel tax. This can be explained by the fact that the tax cost corresponds almost entirely to the original fuel cost, in addition to which a longer flight consumes more fuel. All tax revenues increased as the route distance increased, which can be explained with higher passenger volumes and fuel consumption levels on longer routes. The smallest tax revenues were collected from emissions trading.

5 Discussion

Based on the existing literature, some of the calculated emissions in this study were significantly lower compared to the existing estimates, such in the case of emissions trading. It is difficult to evaluate with certainty the causes for such differences, as all explanatory variables were not presented in a comprehensive way to assess the causes. However, there are two potential explanations. First, the calculations included variables and assumptions excluded from this study, and second, the calculations have assumed that the decrease in demand is directly proportional to the emission reduction. For the latter, we can conclude that this is not the case, as we have shown in this study. In addition, some of the price increases caused by the policy instruments were significantly higher than the estimates of this study, and some were surprisingly close. For example, a study made by Krenek and Schratzenstaller (2016) claimed that with 30€ carbon-based ticket tax, the airfares on an intra-EEA flight would increase approximately 5%, which would result in a 3.5% decrease in passenger demand. In this study, the corresponding figures were with 11.77€ ticket tax +5.5% increase in the ticket price and -9.6% decrease in passenger demand. The figures can be considered very consistent, given the lower demand price elasticity used by Krenek and Schratzenstaller. However, the tax revenues obtained from the use of ticket tax on the given route were three times higher in this study.

Generally, the obtained results of this study were in line with the theory showing that the use of most of the policy instruments will typically increase the airfares, which eventually results in a decreased passenger demand. However, in the case of ticket tax and VAT on flight tickets, the impact of the policy instrument was "a priory ambiguous" meaning, that the use of the policy instrument can both decrease or increase the ticket price received by the airline. The impact of these two taxes are dependent on multiple factors, such as the price sensitivity, and the price ratio between the pre- and post-tax ticket prices.

In the long-term, airlines have multiple ways to respond to variables that affect operational stability. This is particularly affected by the market structure and the taxable item. For example, let us assume that a fuel tax has been levied on kerosene jet fuel. To maintain its ticket prices at a competent level, the airline has now two potential ways to react. First, it could try to improve its fuel efficiency by operating on more energy-efficient aircrafts, or by using less-emitting jet fuels to lower its level of jet fuel consumption, and thus minimize its tax (and fuel) costs. Second, it might try to maximize its sales revenue, for example by marketing, to correspond to the rising costs by increasing its passenger load factors. In this case, the fuel tax does not necessarily lead to an increase in airfares but might lower the operating frequency of flights on certain routes. However, since we assume a monopolistic (or oligopolistic) market structure with no abatement technology, we also assume that the adjustment will occur primarily through pricing. Now the airline sets the price at a new, profit-maximizing level also taking into account the levied tax instrument. Since we have excluded different travel classes from our analysis, we have also excluded the option to shift the tax cost to those travel classes where the impact of the tax on demand is minimized. In this scenario, the tax will have very little effect on both the demand and emissions. Finally, we end up to a conclusion (supported both by the theory and numerical analysis) showing that the use of different tax policies will most likely increase flight ticket prices. This can eventually result in decreased passenger demand, especially on extra short- and long-haul flights [Tol, 2007]. However, we assume that fluctuations in demand do not affect the operation of flights, i.e. we exclude the cancellation of flights due to lowered levels in passenger demand. This is because of the fact, that individual routes are part of larger route networks, which may have a significant impact on the airline's competitive position [Cook and Goodwin, 2008].

If we assume a monopolistic market structure, the airlines would now have mainly two different ways to compete with the other airlines. Instead of pricing, it can improve its marketing, or improve the quality of its services. The quality of service can be improved by increasing travel comfort or by offering more extensive services, such as more flexible ticket cancellation conditions.

Despite with comprehensive policy adjustment practices of the focal airlines, the presented tax policies may be favorable for different airlines. As stated by Kesharwani (2001), both the airfares and jet fuel consumption per flown kilometers, tend to be higher on short-haul flights compared to long-haul flights. Now, the fuel tax would most likely have a stronger impact on airlines whose operations are focused on short-haul routes, such as intra-EEA flights.[Kesharwani, 2001] In the case of Europe, this might not necessarily have any significant effects on the movement of people, since some of the passenger demand could shift to rail transport as the flight ticket prices increase. In this way, the demand can be effectively directed towards more environmentally friendly choices. To prevent profit loss from fuel costs, a fuel tax might drive airlines to refuel in areas where fuel tax has not been added to the price of kerosene. The benefit of the other policy instruments, such as the ticket tax and VAT, is that the tax costs from these instruments cannot be avoided by refueling somewhere else. In addition, many airlines hedge their fuels to prevent any loss from jet fuel price fluctuations [Swidan and Merkert, 2019], which might weaken the efficiency of the tax. According to Keen & Strand (2006), the optimal fuel tax rate is the weighted average of jet fuel demand-price elasticity and the elasticity of its potential substitutes [Keen and Strand, 2006], such as synthetic fuels.

In areas, such as Europe, where the EU Emissions Trading Systems is included to cover all intra-EEA flights, it is important to ensure that there will be no double pricing of carbon. To avoid double-counting this means, that a fuel or emissions tax can be levied mainly on inter-EEA flights. Since longer flights typically consume more fuel, a fuel or an emissions tax could be considered especially reasonable and effective for long-haul flights outside the EU. Emissions tax (like emissions trading) is, however, vulnerable to poor carbon pricing, which reduces its potential efficiency. In the case of emissions trading, the development of allowance prices is primarily determined by the set emissions ceiling and the number of the issued allowances.

In the case of aviation, the allowance price development is also affected by whether emissions trading is closed, semi-closed, or open to other sectors. In a closed aviation allowance trading system, the price of one allowance could reach up to 110 - 330€, depending on the growth rate of future emissions trends [Anger and Köhler, 2010]. In addition, the efficiency of emissions trading is impaired by the narrow scope of its activities, and thus a poor coverage of emissions. If EU ETS had been implemented as originally planned, as a *full scope* version -covering all departing and arriving flights in the European Economic Area-, it would cover a third of all the aviation emissions worldwide [Transport & Environment, 2016]. In the implemented - *reduced scope* - version, the same proportion is only 8%. Considering that only 15% of the allowances will be auctioned, only 2.1% of the world's aviation emissions caused by passenger traffic will be left covered by The EU Emissions Trading System in 2017. However, the proportion will be expected to reach 16% in 2036.[Scheelhaase et al., 2018]

There are different interpretations of which instrument combinations could be used to stay within the 2°objective. For example, according to Larkin-Bows (2014), the target can be achieved only due to proper demand management and introduction on biofuels [Bows-Larkin, 2015]. On the other hand, Taktiri et al. (2017), were strictly convinced that since alternative jet fuel barely offer any reductions to emissions at all, they should not be considered in public as a noteworthy measure to meet the objectives set [Takriti et al., 2017]. Demand management and control as proper measures were supported also by Professors Becken & Mackey (2017), who stated that the passenger demand must fall, in order to receive the desired emission reduction targets. It was also added in the end, that off-setting should not be seen as the first, but rather the second or third instrument for the objectives to be met [Becken and Mackey, 2017].

This study shows that the overall potential to reduce emissions on a individual operable flights is low, even if the demand is reduced in a short-term. This is because the share of passenger emissions in total aircraft emissions is very low. This well illustrates the situation where a ticket was levied on intra-EEA flights. The relative emission reduction of 2% was the highest for all given routes and policy instruments, although the ticket tax reduced passenger numbers by a third. However, this finding does not mean that taxation could not have a reducing impact on the air traffic emissions. The impact of tax impact may increase in the long run, when airlines will have the opportunity to redesign the route according to demand. If the demand faces a rapid drop on certain routes, the airlines may have to assess whether the operating frequency of the route should be reduced in the future.

6 Conclusions

This study provides a comprehensive analysis of the effects of different forms of taxation on air traffic emissions on a short-term period. The analysis is made assuming monopolistic market structure where the focal airlines have market power in the absence of abatement technology.

Of the given policy instruments, emissions trading and fuel tax were the only ones where the tax cost was directly related to the amount of emissions, which makes them potentially effective instruments to reduce emissions. However, the impact of both instruments on emissions was negligible, and in the case of ETS, it was already reduced by free allocation. The emissions were reduced the most by ticket taxes and the introduction of VAT on airline tickets. In both cases, the increase in airfares were higher compared to the other instruments, but unlike in the case of VAT, the impact of the ticket tax on the airline's profits was remarkably low. Seat tax was the only instrument that had no impact on emissions, but which nevertheless reduced the airline's profits.

The general conclusion is that with all the policy instruments, the emission reductions remained low with the used tax rates. This finding was not only due to insufficient tax levels but also to the relatively low share of the passengers in the total emissions. Some policy instruments could, however, improve the long-term development of other emission reduction measures. So far, the conventional jet fuel used on international flights has been tax-free due to the Chicago Agreement of 1944 [ICAO, 2006]. The necessity of this practice can be strongly questioned in the current situation, where the use of fossil fuels are increasingly taxed in other sectors. In addition, tax-free fuels on international flights can distort competition and harm market entry of less emitting jet fuels, such as synthetic fuels. In addition, fuel tax would be beneficial even on freight transport alone.[OECD, 2005] According to the parametric analysis, the efficiency of fuel tax as emissions curbing instrument increases alongside the route distance. To avoid double-counting in policy costs, fuel tax could be implemented to cover only inter-EEA flights, whereas the EU ETS covers all domestic and intra-EEA flights. If more significant emissions reductions are desired, introducing ticket tax or VAT on flight ticket alongside the full-scope-version of emissions trading are worth of considering.

Based on the existing literature and this study, it seems, that the only way to achieve significant emission reductions in the short-term would be to cut entire flights [Boon et al., 2007], and to lower operational frequency on routes that do not significantly harm the route networks. This would not necessarily lead to a significant reduction in passenger numbers but could be implemented by increasing the current occupancy rates, which had a global average of approximately 80% in 2017 [EASA, 2019]. During the present climate crisis, it can be discussed whether it is reasonable for an airline to be economically viable to operate flights with such low occupancy rates. From this perspective, tax instruments could be useful as a means of eliminating inefficiencies associated with low passenger load factors.

Since the overall impact of various policy instruments will most-likely vary depending on the airline, its route networks, and customer segment distribution, the future analysis could be extended by considering such factors as well. Some possible extensions could be applied also including other forms of policy adaptation (including the inclusion of technological developments) and the long-term adaptation strategies.

If the aviation sector does not manage to reduce its emissions, the mitigation actions must be implemented more rigorously in other sectors to meet the global climate goals. The later is the aviation emission peak achieved, the steeper the subsequent emission reductions need to be in the future.[Bows-Larkin, 2015] In a lack of major breakthroughs in technology, it is important to start driving measures and instruments already now. In terms of the alarming predictions of the future of humankind, rapid and real - not just accountable- emission deductions are absolutely necessary.

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